NISTIR 5984

A Summary of Cyclic Lateral Load Tests on Rectangular Reinforced Concrete Columns

Building and Fire Research Laboratory
National Institute of Standards and Technology
Gaithersburg, Maryland 20899

United States Department of Commerce
Technology Administration
National Institute of Standards and Technology

NISTIR 5984

A Summary of Cyclic Lateral Load Tests on Rectangular Reinforced Concrete Columns

January 1997

Andrew W. Taylor, Cynthia Kuo, Kevin Wellenius, Duke Chung

Building and Fire Research Laboratory
National Institute of Standards and Technology
Gaithersburg, Maryland 20899

U.S. Department of Commerce
William Daley, *Secretary*
Technology Administration
Mary **L.** Good, *Under Secretary for Technology*
National Institute of Standards and Technology
Arati A. Prabhakar, *Director*

ABSTRACT

Data are summarized from 107 laboratory tests on reinforced concrete columns with rectangular cross sections. In these tests the axial load on the column was held nearly constant while cyclic lateral loads were applied to cause column deformations in the inelastic range. The data in this report were obtained from test programs in the United States, Canada, New Zealand, and Japan. Synopses of each test program are presented and the geometric and material properties of each column test specimen are summarized. Plots of lateral load vs. lateral deflection are also shown for each specimen. The lateral load-lateral deflection histories for all specimens are presented in digital format on a computer disk. Much of this data has only been available in analog format, and is presented for the first time in digital format in this report.

KEYWORDS: building technology; cyclic lateral loads; digital data base; earthquake engineering; experiments; inelastic behavior; rectangular reinforcement; reinforced concrete columns

ACKNOWLEDGMENTS

We would like to thank the many researchers who provided reports and data to be included in this summary. In a number of cases we requested authors to retrieve data from experiments completed several years before, and they graciously searched their archives for the information we requested. This project was funded by the Federal Highway Administration, the National Center for Earthquake Engineering Research, and the California Department of Transportation. The authors gratefully acknowledge this support.

CONTENTS

Chapter 1: Introduction

The purpose of this document is to summarize and make available for general use a substantial body of experimental data from cyclic lateral load tests on rectangular reinforced concrete columns. These data were collected, digitized and summarized as part of a larger study of the seismic performance of bridge piers[1], conducted in the Building and Fire Research Laboratory of the National Institute of Standards and Technology. It is hoped that this data will be useful to other researchers, especially for the calibration of damage models.

Lateral force-lateral deflection data were obtained from 107 column tests conducted by researchers in the United States, Canada, New Zealand and Japan. While the data set is not exhaustive, it represents a significant portion of the available test data.

In some cases the authors were able to obtain digital lateral force-lateral deflection data directly from the researchers who performed the column tests. In the majority of cases, however, precision photo-enlargements of lateral force-lateral deflection plots were prepared from report figures. These enlargements were then digitized manually using a digitizing tablet. Thus, the accuracy of the data was limited by the accuracy of the published figures.

Not every test from every test series was reported in this summary. For some specimens analog plots were either not available or were not clear enough to be used for digitization. Only data from specimens with a constant axial compressive load (not a fluctuating, tensile, or zero axial load) were digitized. Furthermore, only data from specimens in which the lateral load was applied along one of the principal axes of the cross section (not along the diagonal of the cross section or along a bi-direction loading path) were digitized.

The data are reported in Chapters 2 through 4 of this report. In Chapter 2 a summary of each test program is given. This includes bibliographic citations, a brief description of the test program, loading conditions, scale, material properties, geometry, and so on. The names of digital files containing lateral force-lateral deflection data are also given. In Chapter 3 plots of lateral force vs. lateral deflection are presented for all 107 specimens. Finally, in Chapter 4, the digital test data are presented by means of computer disks.

[1] Stone, William C.; and Taylor, Andrew W., "Seismic Performance of Circular Bridge Columns Designed in Accordance With AASHTO/CALTRANS Standards," NIST Building Science Series 170, Structures Division, Building and Fire Research Laboratory, National Institute of Standards and Technology, Gaithersburg, Maryland, 20899, February **1993.**

Chapter 2: Description of Cyclic Lateral Load Tests on Rectangular Reinforced Concrete Columns

Three types of specimens were tested in the experimental programs described in this report: simple cantilever specimens (Figure 1); double-ended specimens (Figure *2);* and double curvature specimens (Figure 3). To present the data from these three types of specimens in a uniform format, all data is reported in terms of an equivalent simple cantilever column. Thus, for cantilever specimens (Figure 1) the forces and deflections reported are simply the same as those reported by the original researchers. For double ended specimens (Figure *2)* the lateral forces reported are one-half the forces applied to the central stub of the specimen, and the lateral deflections reported are the lateral deflections of the central stub relative to the two fixed end points. For double curvature specimens (Figure 3) the lateral forces reported are those applied to each end beam of the specimen, and the lateral deflections reported are one-half the relative lateral displacements of the two end beams. The reported length "L" of each specimen is shown in Figures 1 to 3.

All data shown in the tables of this chapter were those reported by the researchers performing the original study, unless noted by an asterisk. Data noted by an asterisk were derived from data supplied in the original report. Caution should be exercised in interpreting the values of "transverse reinforcement ratio." Some researchers computed the transverse reinforcement ratio as a volumetric ratio, while others computed it in the same manner as the shear reinforcement ratio is computed for a flexural member. Therefore, to insure a uniform interpretation of the term "transverse reinforcement ratio", when using the data given in this report the ratio should be re-calculated for the specific purpose at hand, based on the geometric data presented in the sketch of each cross section.

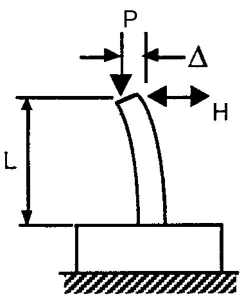


Figure 1: Schematic of Cantilever Specimen

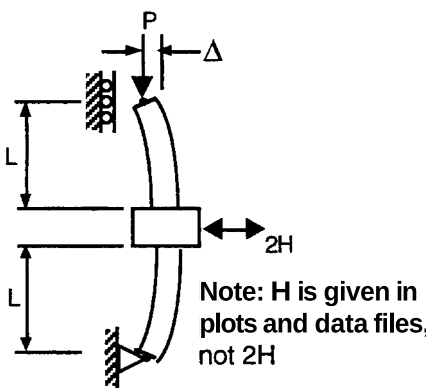


Figure *2:* Schematic of Double Ended Specimen

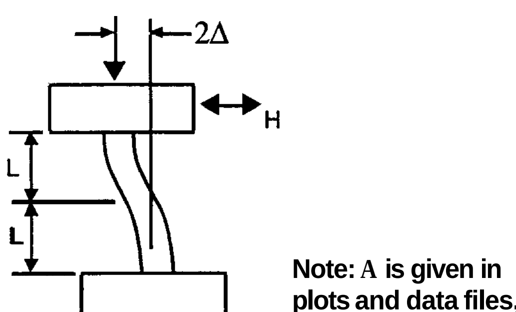
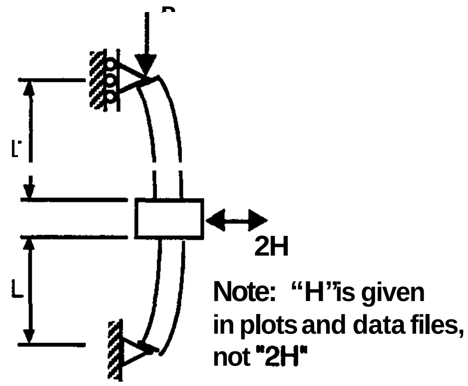
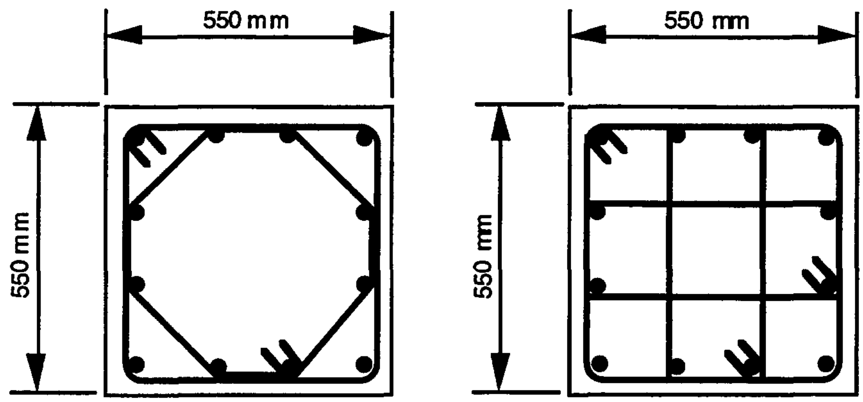


Figure 3: Schematic of Double Curvature Specimen

A: Tests Conducted in New Zealand

1979 Gill





Units 1 and 2 — Units 3 and 4

Gill, Wayne Douglas; Park, R.; and Priestley, M.J.N., "Ductility of Rectangular Reinforced Concrete Columns With Axial Load," Report 79-1, Department of Civil Engineering, University of Canterbury, Christchurch, New Zealand, February 1979, 136 pages.

Also reported in Park, R., Priestley, M.J.N., and Gill, W.D., "Ductility of Square-Confined Concrete Columns," Journal of the Structural Division, ASCE, Vol. 108, No. ST4, April 1982, pp. 929-950.

Master of Engineering Report by Gill. Four full-size column sections were subjected to a static cyclic lateral load sequence over a range of axial compressive loads. Two different tie arrangements, both conforming to DZ3101 requirements, were used. These tests were conducted using a double-ended specimen, a self-reacting load frame with a hydraulic ram to apply cyclic lateral load, and a universal testing machine to apply constant axial load.

Unit No.	In Plastic Hinge Region			Outside Plastic Hinge Region		
	No. of Hoop Sets	Bar dia. mm	Spacing (ctrs.) mm	No. of Hoop Sets	Bar dia. mm	Spacing (ctrs.) mm
1	8	10	80	5	10	135
2	8	12	75	3	12	210
3	8	10	75	6	10	105
4	10	12	72	3	12	200

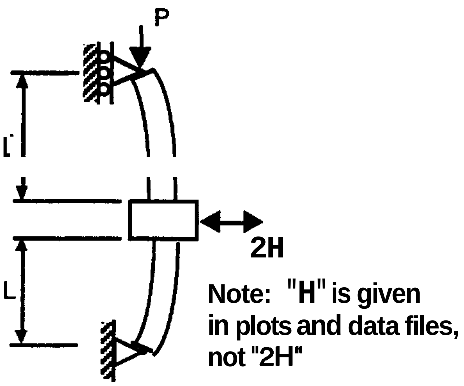
Unit No.	Concrete Strength, MPa	Axial Load kN	Axial Load / Axial Capacity	Longitudinal Reinforcement		Transverse Reinforcement	
				ρ	f_y MPa	ρ	f_y MPa
1	23.1	1815	0.260	0.0179	375	0.015	297
2	41.4	2680	0.214	0.0179	375	0.023	316
3	21.4	2719	0.420	0.0179	375	0.020	297
4	23.5	4265	0.600	0.0179	375	0.035	294

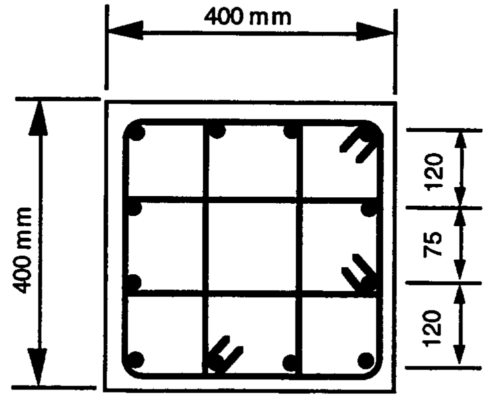
Longitudinal steel - Grade 380 deformed bars, twelve 24 mm dia. with 50 mm cover.
Hoop steel - Grade 275 plain round bars.

Half length of specimen, L = 1.2 m

Data Files: GILL79S1.WK1
GILL79S2.WK1
GILL79S3.WK1
GILL79S4.WK1

1981 Ang, Priestley and Park





Ang Beng Ghee; Priestley, M.J.N.; and Park, R., "Ductility of Reinforced Concrete Bridge Piers Under Seismic Loading," Report 81-3, Department of Civil Engineering, University of Canterbury, Christchurch, New Zealand, February 1981, 109 pages.

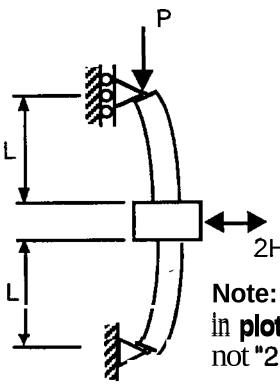
Ang tested four columns designed according to the Second Draft (1980) of the Concrete Design Code DZ3101 for different load levels. Only two involved square (rectangular) columns. These tests were conducted using a double-ended specimen, a self-reacting load frame with a hydraulic ram to apply cyclic lateral load, and a universal testing machine to apply constant axial load.

unit No.	In Plastic Hinge Region			Outside Plastic Hinge Region		
	No. of Hoop Sets	Bar dia. mm	Spacing (ctrs.) mm	No. of Hoop Sets	Bar dia. mm	Spacing (ctrs.) mm
3	5	12	100	6	10	180
4	5	10	90	6	10	180

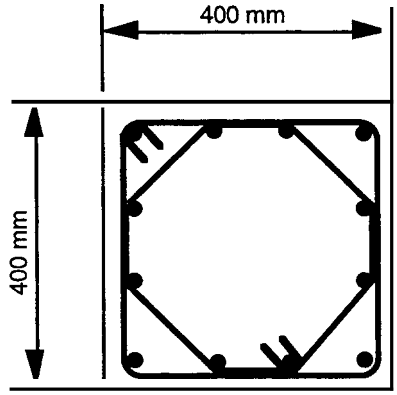
Unit No.	Concrete Strength, MPa	Axial Load kN	Axial Load / Axial Capacity	Longitudinal Reinforcement		Transverse Reinforcement	
				ρ	f_y MPa	ρ	f_y MPa
3	23.6	1435	0.38	0.0151	427	0.02832	320
4	25.0	840	0.21	0.0151	427	0.02218	280

Data Files: *ANG*81U3.WK1
*ANG*81U4.WK1

1986 Soesianawati, Park and Priestley



Note: "H" is given in **plots and data files,** not "2H"



Units 1, 2, 3 and 4

Soesianawati, M.T.; Park, R.; and Priestley, M.J.N., "Limited Ductility Design of Reinforced Concrete Columns," Report 86-10, Department of Civil Engineering, University of Canterbury, Christchurch, New Zealand, March 1986, 208 pages.

Four columns of square cross-section were tested; the quantity of transverse confining steel used ranged from 17 to 46 percent of the **NZS** 3101:1982 recommended quantity for ductile detailing. These tests were conducted using a double-ended specimen, **a** self-reacting load frame with a hydraulic ram to apply cyclic lateral load, and a universal testing machine to apply constant axial load.

Unit No.	In Plastic Hinge Region			Outside Plastic Hinge Region		
	No. of Hoop Sets	Bar dia. mm	Spacing (ctrs.) mm	No. of Hoop Sets	Bar dia. mm	Spacing (ctrs.) mm
1	5	7	85	6	7	170
2	8	8	78	5	8	156
3	7	7	91	5	7	182
4	7	6	94	5	6	186

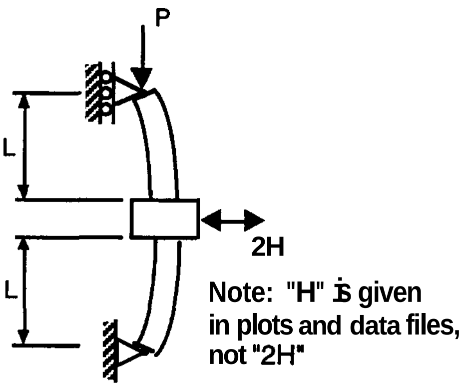
Unit No.	Concrete Strength, MPa	Axial Load kN	Axial Load / Axial Capacity	Longitudinal Reinforcement		Transverse Reinforcement	
				ρ	f_y MPa	ρ	f_y MPa
1	46.5	744	0.1	0.0151	446	0.0086	364
2	44.0	2112	0.3	0.0151	446	0.0122	360
3	44.0	2112	0.3	0.0151	446	0.0080	364
4	40.0	1920	0.3	0.0151	446	0.0057	255

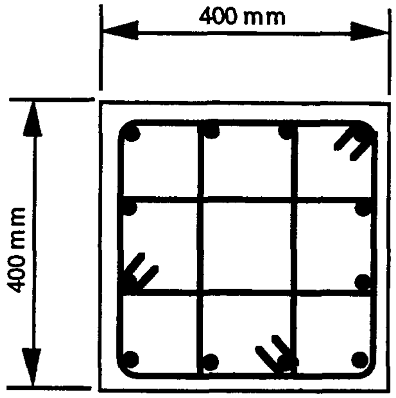
Longitudinal steel - Grade 380 deformed bars, twelve 16 mm dia. bars
Hoop steel - Grade 275 plain round bars. Clear cover to transverse bars = 13 mm.

Half length of specimen, L = **1.6** m

Data Files: SOES86U1.WK1
SOES86U2.WK1
SOES86U3.WK1
SOES86U4.WK1

1986 Zahn, Park and Priestley





Units 7 and 8

Zahn, F.A.; Park, R.; and Priestley, M.J.N., "Design of Reinforced Concrete Bridge Columns for Strength and Ductility," Report 86-7, Department of Civil Engineering, University of Canterbury, Christchurch, New Zealand, March 1986, 330 pages.

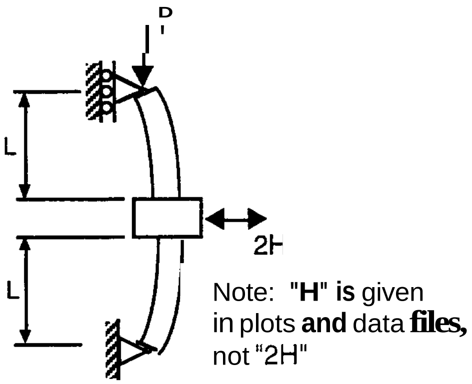
Originally written as a PhD thesis by Zahn. Sixteen specimens were tested with various shapes and load orientation, but only Units 7 and 8 were square with loading along a principal axis of the cross-section. These tests were conducted using a double-ended specimen, a self-reacting load frame with a hydraulic ram to apply cyclic lateral load, and a universal testing machine to apply constant axial load.

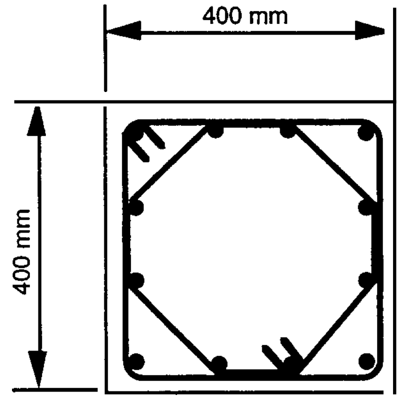
unit No.	In Plastic Hinge Region		
	No. of Hoop Sets	Bardia. mm	Spacing (ctrs.) mm
7	4	10	117
8	7	10	92

Unit No.	Concrete Strength, MPa	Axial Load kN	AxialLoad / Axial Capacity	Longitudinal Reinforcement		Transverse Reinforcement	
				ρ	f_y MPa	ρ	f_y MPa
7	28.3	1010	0.23	0.0151	440	0.0156	466
8	40.1	2502	0.39	0.0151	440	0.0199	466

Data Files: ZAHN86U7.WK1
ZAHN86U8.WK1

1989 Watson and Park





Units 1, 2, 3 and 4

Watson, Soesianawati; and Park, R., "Design of Reinforced Concrete Frames of Limited Ductility," Report 89-4, Department of Civil Engineering, University of Canterbury, Christchurch, New Zealand, January 1989, 232 pages.

PhD thesis by Watson (*née* Soesianawati). Seven specimens were tested, but only Units 5 through 9 were rectangular. These tests were conducted using a double-ended specimen, a self-reacting load frame with a hydraulic ram to apply cyclic lateral load, and a universal testing machine to apply constant axial load.

Unit No.	In Plastic Hinge Region		
	No. of Hoop Sets	Bardia. mm	Spacing (ctrs.) mm
5	8	8	81
6	7	6	96
7	7	12	96
8	-		77
9	12	12	52

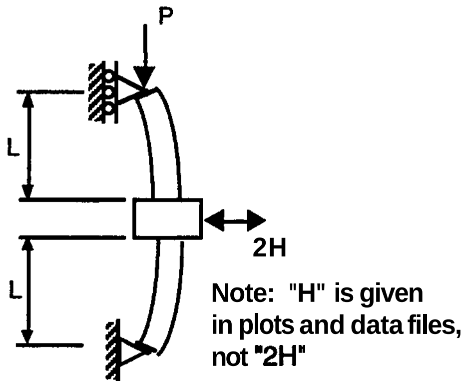
Unit No.	Concrete Strength, MPa	Axial Load kN	Axial Load / Axial Capacity	Longitudinal Reinforcement		Transverse Reinforcement	
				ρ	f_y MPa	ρ*	f_y MPa
5	41	3280	0.5	0.0151	474	0.0066	372
6	40	3200	0.5	0.0151	474	0.0032	388
7	42	4704	0.7	0.0151	474	0.0126	308
8	39	4368	0.7	0.0151	474	0.0070	372
9	40	4480	0.7	0.0151	474	0.0233	308

Longitudinal steel - Grade 380 deformed bars, twelve 16 mm dia. bars
Hoop steel - Grade 275 plain round bars. Clear cover to transverse bars = 13 mm.
* Calculated from data given in report

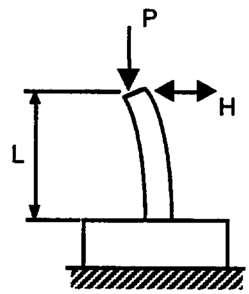
Half length of specimen, L = 1.6 m

Data Files: WAT89U5.WK1
WAT89U6.WK1
WAT89U7.WK1
WAT89U8.WK1
WAT89U9.WK1

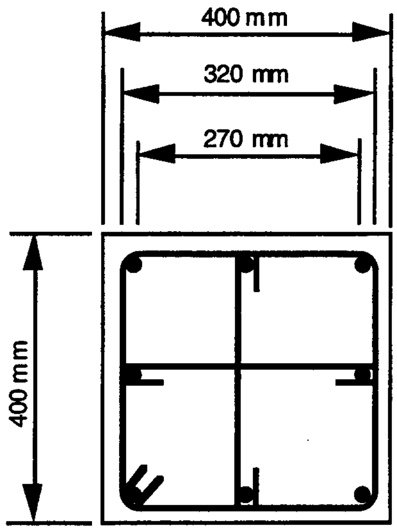
1990 Tanaka and Park



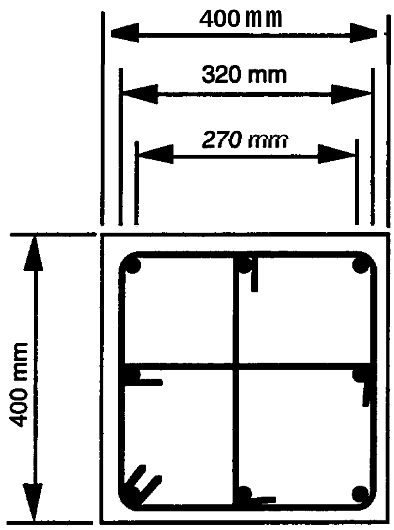
Specimens 1 to 4



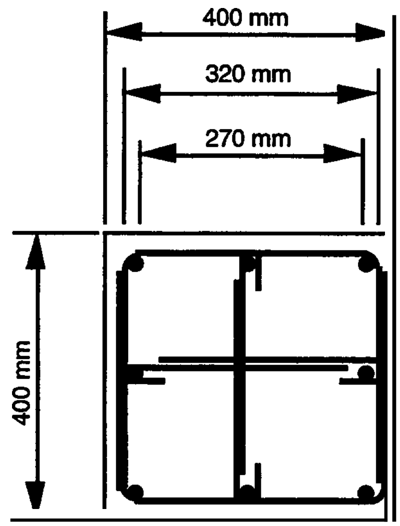
Specimens 5 to 8



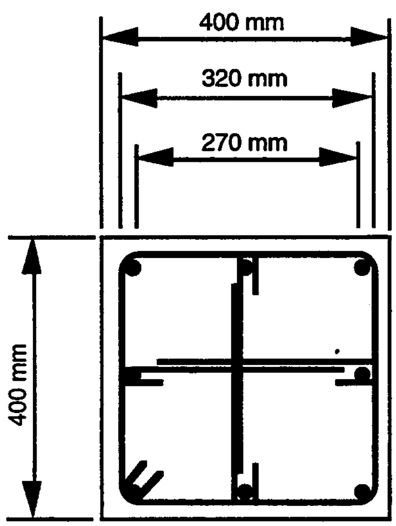
Specimen 1



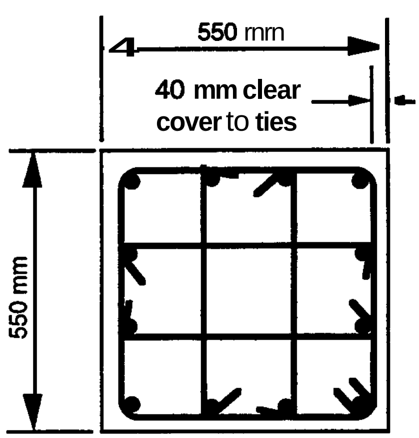
Specimen 2
(Hooks alternate side to side along column)



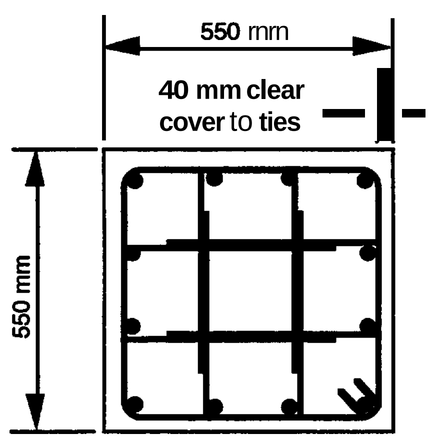
Specimen 3
(Load direction ⟷)



Specimen 4
(Load direction ⟷)



Specimens 5 and 7



Specimens 6 and 8

Tanaka, H.; and Park, R., "Effect of Lateral Confining Reinforcement on the Ductile Behaviour of Reinforced Concrete Columns," Report 90-2, Department of Civil Engineering, University of Canterbury, June 1990,458 pages.

PhD thesis by Tanaka. Eight columns with square cross sections were tested. (One specimen with a rectangular cross section was also tested, as described in the next section). Specimens one through four were conducted using a double-ended specimen, a self-reacting load frame with a hydraulic ram to apply cyclic lateral load, and a universal testing machine to apply constant axial load. Specimens five through eight incorporated a true cantilever column setup.

Unit No.	In Plastic Hinge Region		
	No. of Hoop Sets	Bar dia. mm	Spacing (ctrs.) mm
1	6	12	80
2	6	12	80
3	6	12	80
4	6	12	80
5	6	12	110
6	6	12	110
7	7	12	90
8	7	12	90

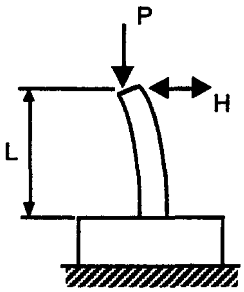
Unit No.	Concrete Strength, MPa	Axial Load kN*	Axial Load / Axial Capacity	Longitudinal Reinforcement		Transverse Reinforcement	
				ρ	f_y MPa	ρ	f_y MPa
1	25.6	819	0.2	0.0157	474	0.0255	333
2	25.6	819	0.2	0.0157	474	0.0255	333
3	25.6	819	0.2	0.0157	474	0.0255	333
4	25.6	819	0.2	0.0157	474	0.0255	333
5	32.0	968	0.1	0.0125	511	0.0170	325
6	32.0	968	0.1	0.0125	511	0.0170	325
7	32.1	2913	0.3	0.0125	511	0.0208	325
8	32.1	2913	0.3	0.0125	511	0.0208	325

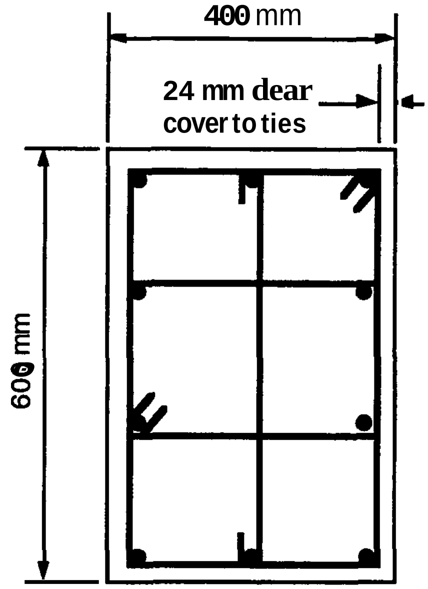
Longitudinal steel - Grade 380 deformed bars, 20 mm dia. bars
Hoop steel - Grade 275 deformed bars. Clear cover to transverse bars = 40 mm.
* Calculated from data given in report

Half length of specimens 1 to 4, L = 1.6 m. Length of specimens 5 to **8,** L = 1.65 m

Data Files: TANA90U1.WK1
TANA90U2.WK1
TANA90U3.WK1
TANA90U4.WK1
TANA90U5.WK1
TANA90U6.WK1
TANA90U7.WK1
TANA90U8.WK1

1990 Park and Paulay





Specimen 9

Park, R.; and Paulay, T., "Use of Interlocking Spirals for Transverse Reinforcement in Bridge Columns," ***Strength and Ductility of Concrete Substructures of Bridges,*** RRU (Road Research Unit) Bulletin **84,** Vol. 1, 1990, pp 77-92.

See also, Tanaka, H.; and Park, R., "Effect of Lateral Confining Reinforcement on the Ductile Behaviour of Reinforced Concrete Columns," Report 90-2, Department of Civil Engineering, University of Canterbury, June 1990, 458 pages, described in the previous section.

One rectangular column with overlapping hoops **was** tested. The configuration of the specimen was a cantilever, **as** illustrated above.

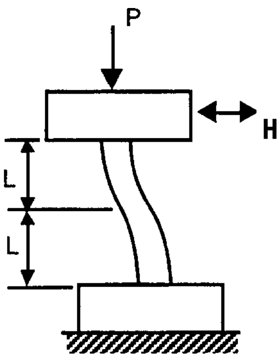
In Plastic Hin e Re 'on

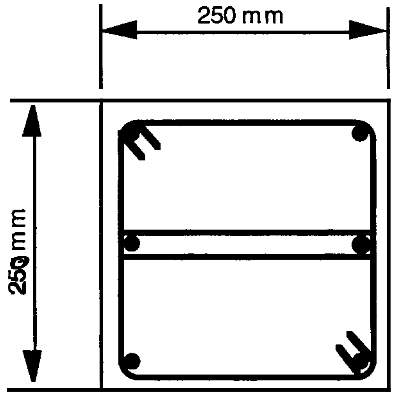
	Hoo Sets	Bar dia.	spacing (ctrs.) mm
9	9	12	80

Unit No.	Concrete Strength, MPa	Axial **Load** kN*	Axial Load / Axial Capacity	Longitudinal Reinforcement		Transverse Reinforcement	
				ρ	f_y MPa	ρ	f_y MPa
9	26.9	646	0.1	0.0188	432	0.0217	305

B. Tests Conducted in Japan

1982 Arakawa, Arai, Egashira, and Fujita





Specimen **102**
(Load Direction ↔)

Unit No.	Lateral Reinforcement	
	Bardia. mm	Spacing (ctrs.) mm
102	5.5	32

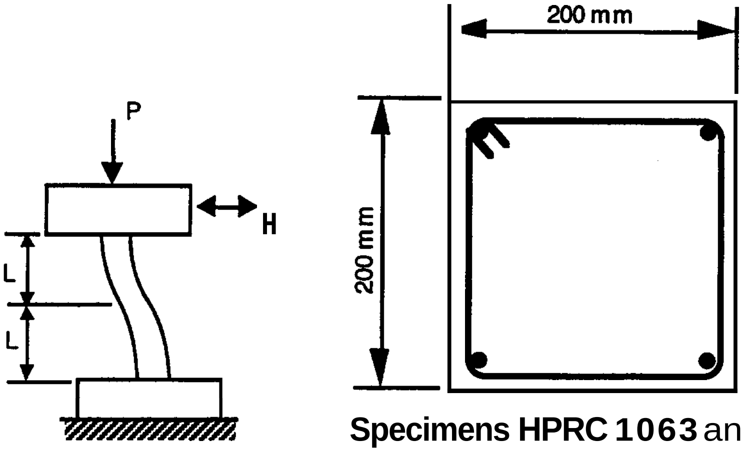
Unit No.	Concrete Strength, MPa	Axial Load **kN***	Axial Load / Axial Capacity	Longitudinal Reinforcement		Transverse Reinforcement	
				P	f_y MPa	P	f_y MPa
102	20.6	429	0.33	0.0068	392.8	0.0118	323

*Calculated from data given in report

Half height of specimen, L = 0.375 m

Data Files: AR82102.WK1

1982 Nagasaka



Specimens HPRC 1063 and1432

Nagasaka, Tomoya, "Effectiveness of Steel Fiber as Web Reinforcement in Reinforced Concrete Columns," ***Transactions of the Japan Concrete Institute,*** Vol. **4, 1982,** pp. **493-500.**

Twenty-two double-curvature specimens were tested under constant axial load and cyclic lateral load. The main variable was the use of conventional hoop reinforcement vs. the use of fiber reinforcement. Digitizable analog plots were available from the paper for only two of the tests that had conventional hoop reinforcement and no fiber reinforcement: specimen HPRC **10-63** and HPRC **19-32.**

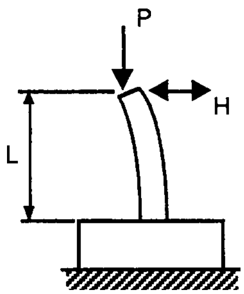
Unit **No.**	Lateral Reinforcement	
	Bardia. mm	Spacing (ctrs.) mm
HPRC **10-63**	**6**	**35**
HPRC **19-32**	**6**	**20**

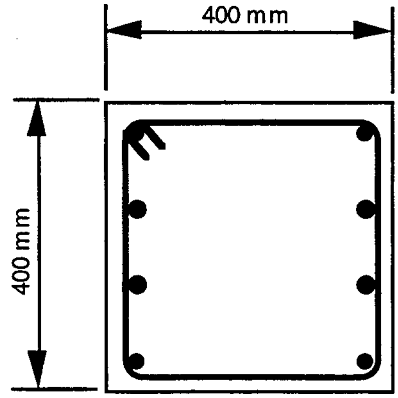
Unit **No.**	Concrete Strength, MPa	Axial Load kN	Axial Load / Axial Capacity*	Longitudinal Reinforcement		Transverse Reinforcement	
				ρ	f_y MPa	ρ	f_y MPa
HPRC **10-63**	**21.6**	**147**	**0.17**	**0.0133**	**371**	**0.0081**	**344**
HPRC **19-32**	**21.0**	**294**	**0.34**	**0.0133**	**371**	**0.0139**	**344**

Half height of specimen, L = **0.30 m**

Data Files: **NAG1063**.WK1
NAG1932.WK1

1984 Ohno and Nishioka





Specimens L1, L2, L3
(Load Direction ⟷)

Ohno, Tomonori; and Nishioka, Takashi, "An Experimental Study on Energy Absorption Capacity of Columns in Reinforced Concrete Structures," ***Proceedings of the*** *JSCE,* ***Structural Engineering/Earthquake Engineering,*** Vol. 1, No 2., October 1984, pp. 137-147.

Five cantilevered columns were tested under constant axial load and cyclic lateral load. The variables studied were the lateral load pattern and the level of axial load. Digitizable analog plots were available for only three of the tests: specimens L1, L2 and L3. The lateral load pattern for specimen L1 was very severe, and only two complete cycles were applied.

Unit No.	Lateral Reinforcement	
	Bardia. mm	Spacing (ctrs.) mm
L1	9	100
L2	9	100
L3	9	100

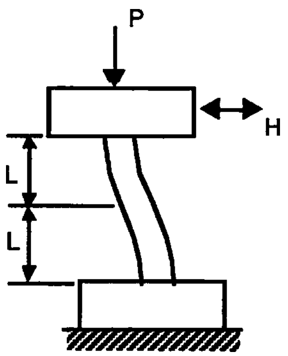
Unit No.	Concrete Strength, MPa	Axial Load kN*	Axial Load / Axial Capacity*	Longitudinal Reinforcement		Transverse Reinforcement	
				ρ*	f_y MPa	ρ	f_y MPa
L1	24.8	157	0.04	0.0142	362	0.0032	325
L2	24.8	157	0.04	0.0142	362	0.0032	325
L3	24.8	157	0.04	0.0142	362	0.0032	325

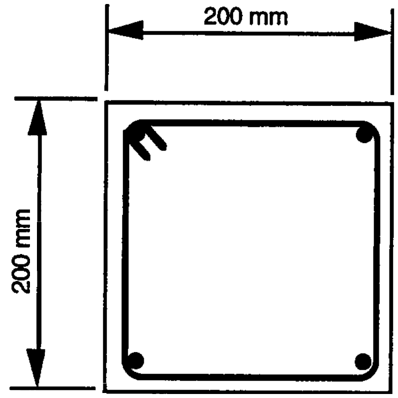
Longitudinal steel - ϵ
* Calculated from data given in report

Height of specimen, L = 1.6 m

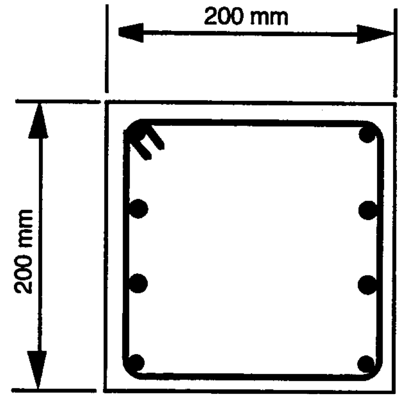
Data Files: OHNO84L1.WK1
OHNO84L2.WK1
OHNO84L3.WK1

1985 Ohue, Morimoto, Fujii and Morita





Specimen 2D16RS
(Hoop comer detail unkown,
135 degree hooks assumed)



Specimen 4D13RS
(Load Direction ⟷)
(Hoop comer detail unkown,
135 degree hooks assumed)

Ohue, Minoru; Morimoto, Hisao, Fujii, Shigeru; and Morita, Shiro, "The Behavior of R.C. Short Columns Failing in Splitting Bond-Shear Under Dynamic Lateral Loading," ***Transactions* of *the Japan Concrete Institute*,** Vol. 7,1985, pp. 293-300.

Eleven double curvature columns were tested under constant axial load and cyclic lateral load. The main variable studied was the rate of lateral loading. Digitizable analog plots were available for only two of the tests in which quasi-static lateral load was applied: specimens 2D16RS and 4D13RS.

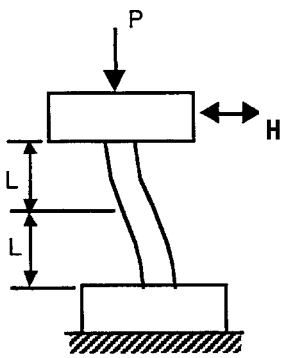
unit No.	Lateral Reinforcement	
	Bardia. mm	Spacing (ctrs.) mm
2D16RS	6	50
4D13RS	6	50

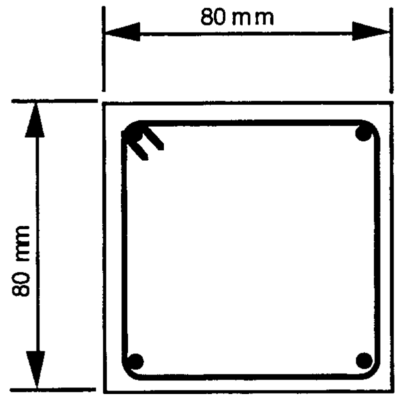
Unit No.	Concrete Strength, MPa	Axial Load kN	AxialLoad / Axial Capacity*	Longitudinal Reinforcement		Transverse Reinforcement	
				ρ*	f_y MPa	P	f_y MPa
2D16RS	32.0	183	0.14	0.0201	369	0.0057	316
4D13RS	29.9	183	0.15	0.0265	370	0.0057	316

Half height of specimen, L = 0.40 m

Data Files: OH2D16RS.WK1
OH4D13RS.WK1

1985 Zhou, Higashi, Jiang, and Shimizu





Specimens 806,1007, and 1309
(Hoop corner detail unkown,
135 degree hooks assumed)

Zhou, Xiaozhen; Higashi, Yoichi; Jiang, Weishan; and Shimizu, Yasushi, "Behavior of Reinforced Concrete Column Under High Axial Load," ***Transactions* of *the Japan Concrete Institute*,** Vol. 7, 1985, pp. 385-392.

Seventeen one-fifth scale, double curvature column specimens were tested. This study focuses on short columns with high axial loads. Only three digitizable analog plots were available from the paper: specimens 806, 1007, and 1309

Unit No.	Lateral Reinforcement	
	Bar dia. mm	Spacing (ctrs.) mm
806	4	80
1007	4	80
1309	4	80

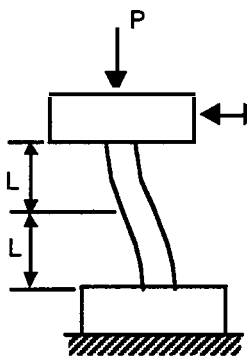
Unit No.	Concrete Strength, MPa	Axial Load kN*	Axial Load / Axial Capacity*	Longitudinal Reinforcement		Transverse Reinforcement	
				ρ*	f_y MPa	ρ*	f_y MPa
806	32.3	124	0.6	0.0177	336	0.0052	341
1007	34.0	152	0.7	0.0177	336	0.0052	341
1309	32.8	189	0.9	0.0177	336	0.0052	341

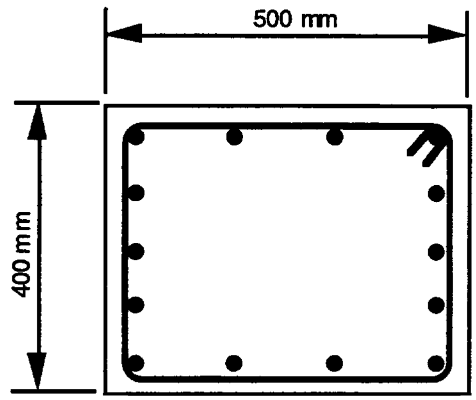
Longitudinal steel - four deformed bars, 6 mm dia
Lateral reinforcement is plain bars (not deformed)
* Calculated from data given in report

Half height of specimen, L = 0.08 m

Data Files: ZHO806.WK1
ZHO1007.WK1
ZHO1309.WK1

1986 Imai and Yamamoto





(Load Direction ←——→)
(Hoop corner detail unkown
135 dgree hooks assumed)

Imai, Hiroshi; and Yamamoto, Yoshie, "A Study on Causes of Earthquake Damage of Izumi High School Due to Miyagi-Ken-Oki Earthquake in 1978," ***Transactions of the Japan Concrete Institute,*** Vol. 8, 1986, pp. 405-418.

One full-size double curvature specimen was tested. The specimen simulated columns in a high school building damaged during the 1978 Miyagi-ken-oki earthquake

unit No.	Lateral Reinforcement	
	Bardia. mm	Spacing (ctrs.) mm
1	9	100

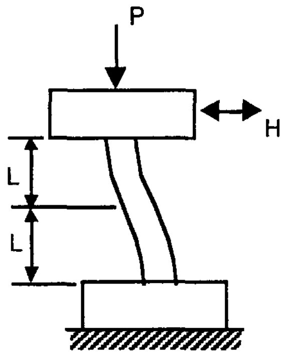
Unit No.	Concrete Strength, MPa	Axial Load kN*	Axial Load / Axial Capacity*	Longitudinal Reinforcement		Transverse Reinforcement	
				ρ*	f_y MPa	p**	f_y MPa
1	27.1	392	0.072	0.0209	318	0.0036	336

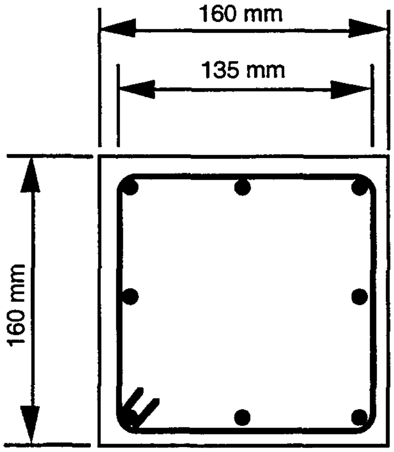
* Calculated from data given in report
**Approximate value estimated from data given in report

Half height of specimen, L = 0.825 m

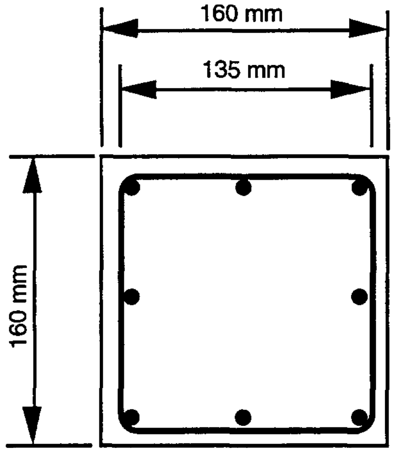
Data Files: IMAI86.WK1

1987 Zhou, Satoh, Jiang, Ono and Shimizu

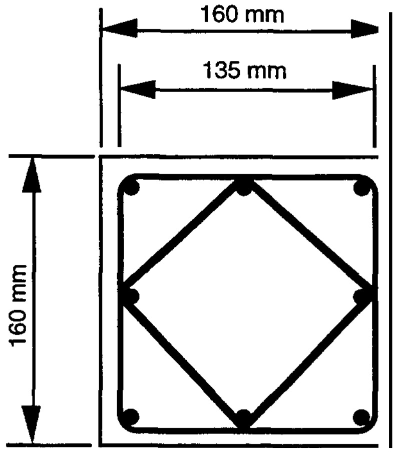




Specimens
104-08,204-08
and 302-07



Spiral hoops
Specimens
114-08,214-08
and 312-07



Double spiral hoops
Specimens
124-08,223-09 and
322-07

Zhou, Xiaoshen; Satoh, Toshio; Jiang, Weishan; Ono, Arata; and Shimizo, Yasushi, "Behavior of Reinforced Concrete Short Column Under High Axial Load," ***Transactions of the Japan Concrete Institute,*** Vol. 9, 1987, pp. 541-548.

Thirty-five double curvature column specimens, at approximately 2/5 scale, were tested under constant axial load and cyclic lateral load. The main objective of the test series was to investigate the seismic performance of columns under high compressive stress. Digitizable analog plots from only nine specimens were available in the paper.

Unit No.	Lateral Reinforcement	
	Bardia. mm	Spacing (ctrs.) mm
104-08	5	40
114-08	5	40
124-08	5	40
204-08	5	40
214-08	5	40
223-09	5	40
302-07	5	40
312-07	5	40
322-07	5	40

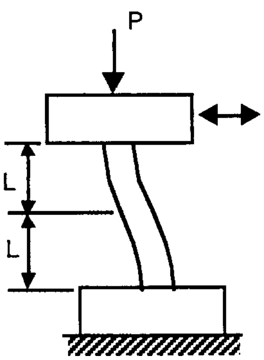
Unit No.	Concrete Strength, MPa	Axial Load kN*	Axial Load / Axial Capacity*	Longitudinal Reinforcement		Transverse Reinforcement	
				ρ*	f_y MPa	ρ*	f_y MPa
104-08	19.8	406	0.8	2.45	341	0.0073	559
114-08	19.8	406	0.8	2.45	341	0.0073	559
124-08	19.8	406	0.8	2.45	341	0.0175	559
204-08	21.1	432	0.8	2.45	341	0.0073	559
214-08	21.1	432	0.8	2.45	341	0.0073	559
223-09	21.1	486	0.9	2.45	341	0.0175	559
302-07	28.8	517	0.7	2.45	341	0.0073	559
312-07	28.8	517	0.7	2.45	341	0.0073	559
322-07	28.8	517	0.7	2.45	341	0.0175	559

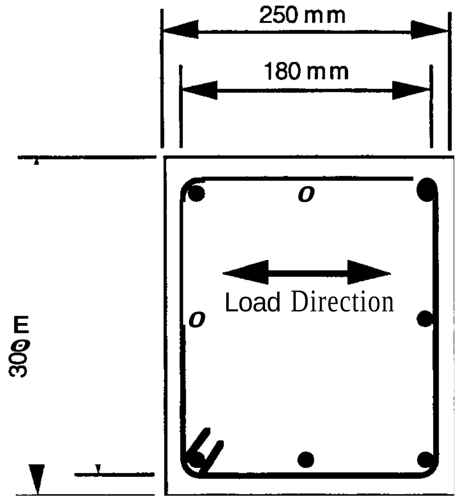
Longitudinal steel - eight bars, 10 mm dia
*Calculated from data given in report

Half height of specimens: 104-08, 114-08 and 124-08, L = 0.16 m
204-08, 214-08 and 223-09, L = 0.32 m
302-07, 312-07 and 322-07, L = 0.48 m

Data Files:
ZHO10408.WK
ZHO11408.WK
ZHO12408.WK
ZHO20408.WK
ZHO21408.WK
ZHO22309.WK
ZHO30207.WK
ZHO31207.WK
ZHO32207.WK

1987 Kanda, Shirai, Adachi and Sato





All **Specimens**
(Hoop detail unclear. **Corner**
hooks **assumed)**

Kanda, Makoto; Shirai, Nobuaki; Adachi, Hiromi; and Sato, Toshio, "Analytical Study on Elasto-Plastic Hysteretic Behaviors of Reinforced Concrete Members," ***Transactions of the Japan Concrete Institute,*** Vol. 10, 1988, pp. 257-264. (Specimens 85STC-3 and 85PDC-3 only)

Six double curvature specimens were tested. In three of the tests ("STC" series) pseudo-static cyclic loads were applied in the form of a sawtooth wave with gradually increasing amplitude. In the remaining three tests ("PDC" series) a pseudo-dynamic testing procedure was followed, to simulate earthquake loading of the columns. The three specimens in each series had different details for anchorage of the longitudinal bars. The influence of the anchorage detail is not discussed in the paper by Kanda et al. because the paper mainly focuses on finite element modeling methods. Digital files of load-deflection data for all six tests were obtained directly from the researchers who performed the tests.

Unit No.	Lateral Reinforcement	
	Bardia. mm	Spacing (ctrs.) mm
85STC-1	6	50
85STC-2	6	50
85STC-3	6	50
85PDC-1	6	50
85PDC-2	6	50
85PDC-3	6	50

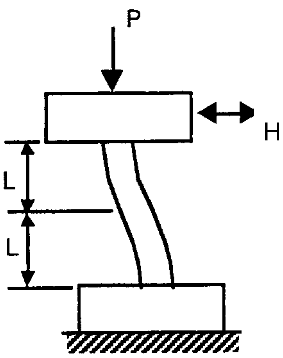
Unit No.	Concrete Strength, MPa	Axial Load kN*	Axial Load / Axial Capacity*	Longitudinal Reinforcement		Transverse Reinforcement	
				ρ*	f_y MPa	ρ*	f_y MPa
85STC-1	27.9	183.9**	0.088	0.0142	374	0.0038	506
85STC-2	27.9	183.9**	0.088	0.0142	374	0.0038	506
85STC-3	27.9	183.9	0.088	0.0142	374	0.0038	506
85PDC-1	24.8	183.9**	0.099	0.0142	338	0.0038	352
85PDC-2	27.9	183.9**	0.088	0.0142	374	0.0038	506
85PDC-3	27.9	183.9	0.088	0.0142	374	0.0038	506

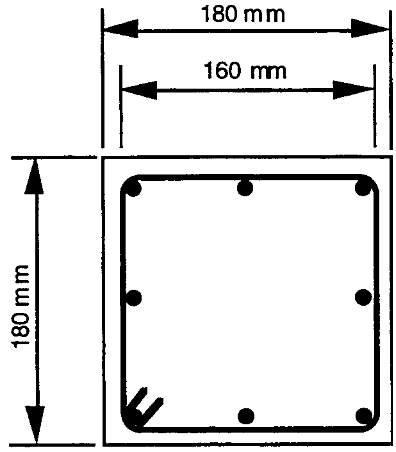
Longitudinal steel - eight deformed bars, 13 mm diameter
Lateral reinforcement - plain bars, 6 mm dia., except deformed bars 6 mm dia for 85PDC-1
*Calculated from data given in report
**Assumed value, inferred from report

Half height of specimens: L=750 mm

Data Files: KANSTC1.WK1
KANSTC2.WK1
KANSTC3.WK1
KANPDC1.WK1
KANPDC2.WK1
KANPDC3.WK1

1989 Arakawa, Arai, Mizoguchi and Yoshida





Specimens OA2 and OA5

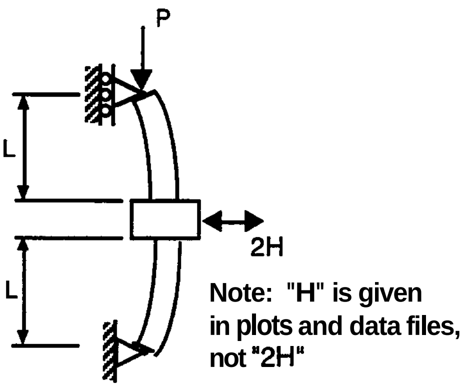
Unit No.	Lateral Reinforcement	
	mm	
OA2	4	64.3
OA5	4	64.3

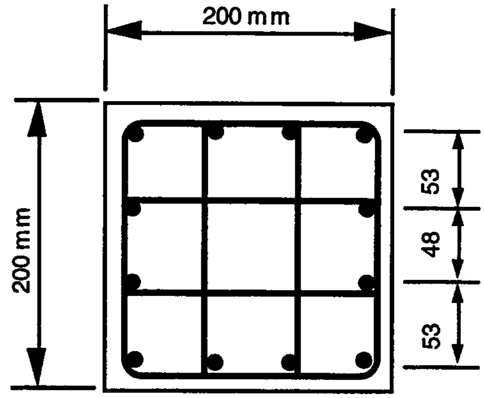
Unit No.	Concrete Strength, MPa	Axial Load kN*	Axial Load / Axial Capacity*	Longitudinal Reinforcement		Transverse Reinforcement	
				ρ*	f_y MPa	ρ*	f_y MPa
OA2	31.8	190	0.185	0.0313	340	0.0024	249
OA5	33.0	476	0.445	0.0313	340	0.0024	249

Half height of specimens: L=225 mm

Data Files: ARA89OA2.WK1
ARA89OA5.WK1

1989 Muguruma, Watanabe and Komuro





All Specimens
(Hoops and lies are welded closed)

unit No.	Lateral Reinforcement	
	Bar dia. mm	Spacing (ctrs.) mm
AH-1	6	35
AL-2	6	35
AH-2	6	35
BL-1	6	35
BH-1	6	35
BL-2	6	35
BH-2	6	35

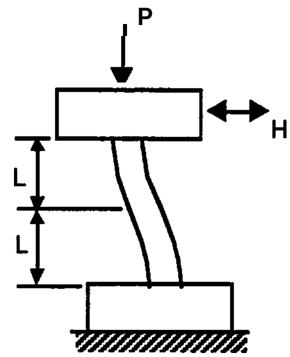
Unit No.	Concrete Strength, MPa	Axial Load kN*	Axial Load / Axial Capacity	Longitudinal Reinforcement		Transverse Reinforcement	
				ρ	f_y MPa	ρ	f_y MPa
AL-1	85.7	1371	0.400	0.0381	399.6	0.0161	328.4
AH-1	85.7	1371	0.400	0.0381	399.6	0.0161	792.3
AL-2	85.7	2156	0.629	0.0381	399.6	0.0161	328.4
AH-2	85.7	2156	0.629	0.0381	399.6	0.0161	792.3
BL-1	115.8	1176	0.254	0.0381	399.6	0.0161	328.4
BH-1	115.8	1176	0.254	0.0381	399.6	0.0161	792.3
BL-2	115.8	1959	0.423	0.0381	399.6	0.0161	328.4
BH-2	115.8	1959	0.423	0.0381	399.6	0.0161	792.3

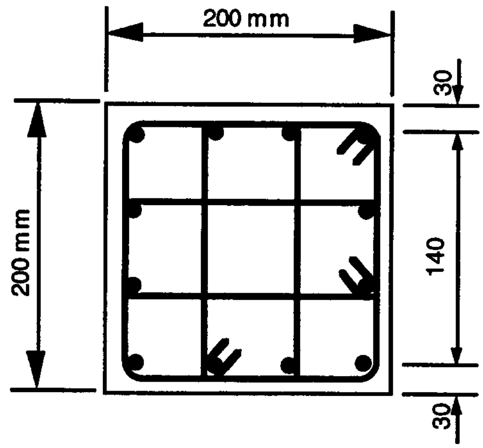
Longitudinal steel - twelve deformed bars, 13 mm diameter
Lateral reinforcement - plain bars, 6 mm in diameter
Clear cover to lateral reinforcement = 9 mm
* Calculated from data given in report

Half height of specimens: L=500 mm

Data Files: MUG89AL1.WK1
MUG89AH1.WK1
MUG89AL2.WK1
MUG89AH2.WK1
MUG89BL1.WK1
MUG89BH1.WK1
MUG89BL2.WK1
MUG89BH2.WK1

1989 Ono, Shirai, Adachi and Sakamaki





Specimens CA025C and CA060C

Ono, Arata; Shirai, Nobuaki; Adachi, Hiromi; and *Sakamaki,* Yoshio, "Elasto-Plastic Behavior of Reinforced Concrete Column With Fluctuating Axial Force," ***Transactions of the Japan Concrete Institute,*** Vol. 11, 1989, pp. 239-246.

Four double curvature specimens were tested. The main variable studied in this series was the axial load level. One specimen was tested with fluctuating axial load; one was tested with axial tension; and two were tested with constant axial compression. Only results from the two tests with constant axial compression are reported here.

unit No.	Lateral Reinforcement	
	Bardia. mm	Spacing (ctrs.) mm
CA025C	6	70
CA060C	6	70

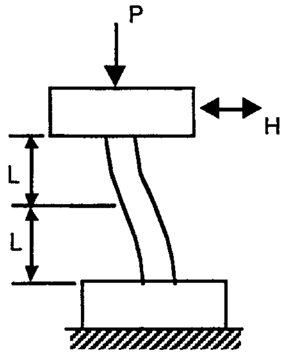
Unit No.	Concrete Strength, MPa	Axial Load kN	Axial Load / Axial Capacity*	Longitudinal Reinforcement		Transverse Reinforcement	
				ρ*	f_y MPa	ρ	f_y MPa
CA025C	25.8	265	0.25	0.0236	361	0.0091	426
CA060C	25.8	636	0.60	0.0236	361	0.0091	426

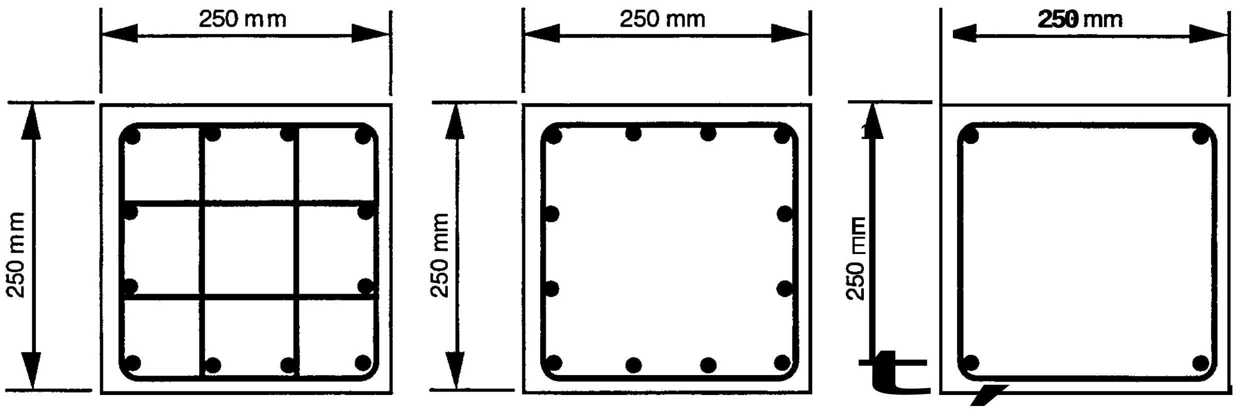
* Calculated from data given in report

Half height of specimens: L=300 mm

Data Files: ONO025C.WK1
ONO060C.WK1

1990 Sakai, Hibi, Otani and Aoyama





Specimens 1, 2, 3, and 4 (Hoops are welded) | **Specimens 5 and 6** (Hoops are welded) | **Specimen 7** (Hoops are welded)

Sakai, Yuuki; Hibi, Junichi; Otani, Shunsuke; and Aoyama, Hiroyuki, "Experimental Study on Flexural Behavior of Reinforced Concrete Columns Using High-Strength Concrete," *Transactions of the Japan Concrete Institute*, Vol. 12, 1990, pp. 323-330.

The main purpose of this study was to investigate the behavior of columns made of high strength concrete. Eight double curvature specimens were tested. Digital data files were obtained directly from the authors. The axial load applied to Specimen B8 was not constant, so results from B8 are not presented here.

Unit No.	Lateral Reinforcement	
	Bar dia. mm	Spacing (ctrs.) mm
B1	5	60
B2	5	40
B3	5.5	60
B4	5	60
B5	5	30
B6	7	60
B7	5	30

Unit No.	Concrete Strength, MPa	Axial Load kN	Axial Load / Axial Capacity*	Longitudinal Reinforcement		Transverse Reinforcement	
				ρ*	f_y MPa	ρ	f_y MPa
B1	99.5	2176	0.35	0.0255	379	0.0050	774
B2	99.5	2176	0.35	0.0255	379	0.0075	774
B3	99.5	2176	0.35	0.0255	379	0.0061	344
B4	99.5	2176	0.35	0.0255	379	0.0050	1126
B5	99.5	2176	0.35	0.0255	379	0.0050	774
B6	99.5	2176	0.35	0.0255	379	0.0050	857
B7	99.5	2176	0.35	0.0181	339	0.0050	774

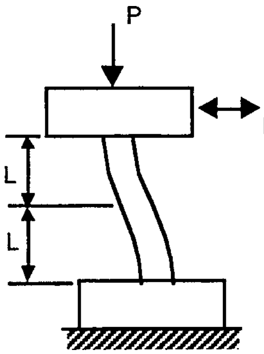
Longitudinal steel - **Specimens B1 to B6, twelve 13** mm **diameter deformed bars**
Specimen B7, four 19 mm diameter deformed bars

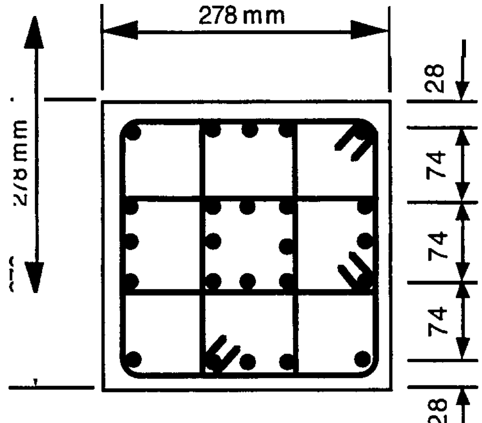
* **Calculated from** data **given in report**

Half height of specimens: L = 500 mm

Data Files: SAK90B1.WK1
SAK90B2.WK1
SAK90B3.WK1
SAK90B4.WK1
SAK90B5.WK1
SAK90B6.WK1
SAK90B7.WK1

1991 Amitsu, Shirai, Adachi and Ono





Specimen CB060C

Amitsu, Shigeyuki; Shirai, Nobuaki; Adachi, Hiromi; and Ono, Arata, "Deformation of Reinforced Concrete Column with High or Fluctuating Axial Force," *Transactions of the Japan Concrete Institute*, Vol. 13, 1991, pp. 355-362.

Three double curvature specimens were tested at 1/3.25 scale. Only one specimen was tested with a constant axial force. As shown in the sketch above, the configuration of the longitudinal reinforcement **was** unusual.

Unit No.	Lateral Reinforcement	
	Bar dia. mm	Spacing (ctrs.) mm

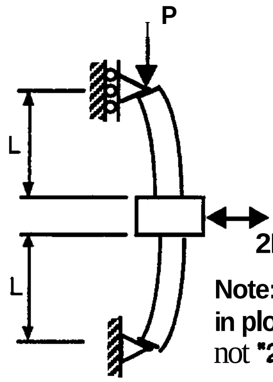
Unit No.	Concrete Strength, MPa	Axial Load kN	Axial Load / Axial Capacity	Longitudinal Reinforcement		Transverse Reinforcement	
				ρ*	f_y MPa	ρ	f_y MPa
CB060C	46.3	2632	0.74	0.0412	441	0.0089	414

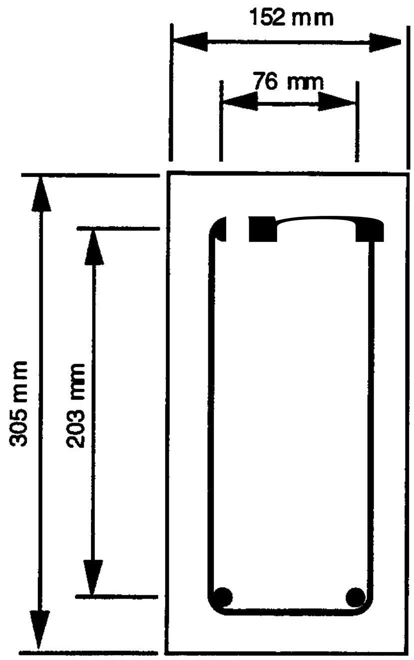
Half height of specimen: L=323 mm

Data File: AMCB060C.WK1

C. Tests Conducted in North America

1973 Wight and Sozen





(hoops are welded)

Wight, J.K.; and Sozen, M.A., "Shear Strength Decay in Reinforced Concrete Columns Subjected to Large Deflection Reversals," ***Structural Research Series No. 403,*** Civil Engineering Studies, University of Illinois, Urbana-Champaign, Ill., Aug. 1973, 290 pages.

The main variables studied in this series were the axial load level, the transverse reinforcement content, and the displacement ductility demand. Twelve double-ended specimens were tested, but axial load was applied to only seven of the specimens. The central stub of each column was clamped so that it was immobile. Axial loads were applied by a self-reacting system of high strength steel rods and hydraulic ram. Lateral loads were applied by actuators at each end of the specimen; bending was about the strong axis of the cross section. Data was given for each end of the specimen, so in this report 14 load-displacement plots are presented: two plots for each axially loaded specimen.

Unit No.	Lateral Reinforcement	
	Bar dia. mm	Spacing (ctrs.) mm
40.033a	6.3	127
40.048	6.3	89
40.033	6.3	127
25.033	6.3	127
40.067	6.3	64
40.147	9.5	64
40.092	9.5	102

Unit No.	Concrete Strength, MPa	Axial Load kN	Axial Load / Axial Capacity*	Longitudinal Reinforcement		Transverse Reinforcement	
				ρ*	f_y MPa	ρ	f_y MPa
40.033a	34.7	189	0.12	0.0061	496	0.0033	345
40.048	26.1	178	0.15	0.0061	496	0.0048	345
40.033	33.6	178	0.11	0.0061	496	0.0033	345
25.033	33.6	111	0.07	0.0061	496	0.0033	345
40.067	33.4	178	0.11	0.0061	496	0.0067	345
40.147	33.5	178	0.11	0.0061	496	0.0147	317
40.092	35.5	178	0.11	0.0061	496	0.0092	317

Longitudinal steel - 4 deformed bars, 19 mm dia

Lateral reinforcement: 6.3 mm dia. bars are undeformed; 9.5 mm dia. bars are deformed

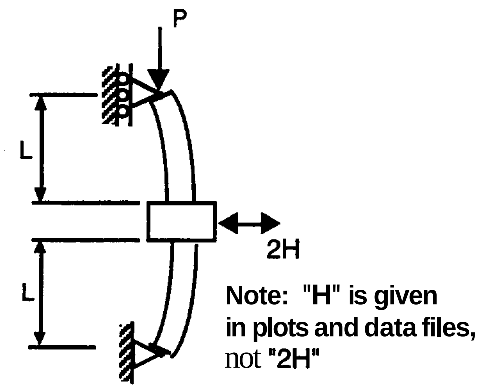
*Calculated from data given in report

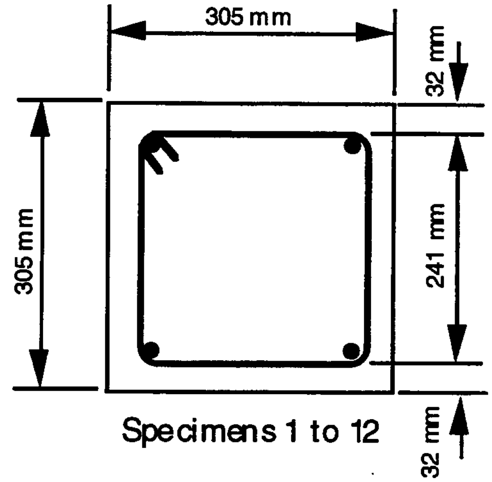
Half height of specimens: L=876 mm

Data Files:

WS25033E.WK1
WS25033W.WK1
WS033AE.WK1
WS033AW.WK1
WS033E.WK1
WS033W.WK1
WS048E.WK1
WS048W.WK1
WS067E.WK1
WS067W.WK1
WS092E.WK1
WS092W.WK1
WS147E.WK1
WS147W.WK1

1975 Atalay and Penzien





Specimens 1 to 12

Atalay, M.B.; and Penzien, J., 'The Seismic Behaviour of Critical Regions of Reinforced Concrete Components as Influenced by Moment, Shear and Axial Force," Report No. EERC 75-19, University of California, Berkeley, Dec. 1975, 226 pages.

The main variables studied in this series were the level of axial stress; the quantity of lateral reinforcement; and the displacement history applied to the specimen. Twelve double-ended specimens were tested, however, only ten of the analog load-deflection plots could be digitized. The two ends of each specimen had pinned boundary condition, and cyclic lateral displacements were applied to the central stub. Axial loads were applied by a hydraulic actuator reacting against a buttress. (Note that a second loading sequence was applied to specimens 1 to **8,** but data from the second loading sequence is not reported here).

unit No.	Lateral Reinforcement	
	Bardia. mm	Spacing (ctrs.) mm
1S1	9.5	76
2s1	9.5	127
3S1	9.5	76
4S1	9.5	127
5S1	9.5	76
6S1	9.5	127
9	9.5	76
10	9.5	127
11	9.5	76
12	9.5	127

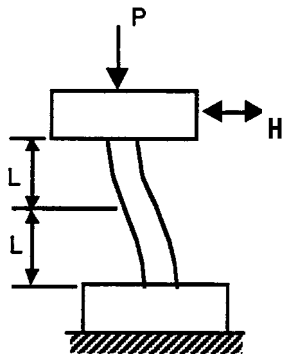
Unit No.	Concrete Strength, MPa	Axial Load kN	Axial Load / Axial Capacity*	Longitudinal Reinforcement		Transverse Reinforcement	
				ρ*	f_y MPa	ρ	f_y MPa
1S1	29.1	267	0.099	0.0167	367	0.0154	363
2S1	30.7	267	0.094	0.0167	367	0.0093	363
3S1	29.2	267	0.098	0.0167	367	0.0154	363
4S1	27.6	267	0.104	0.0167	429	0.0093	363
5S1	29.4	534	0.196	0.0167	429	0.0154	392
6S1	31.8	534	0.181	0.0167	429	0.0093	392
9	33.3	801	0.259	0.0167	363	0.0154	392
10	32.4	801	0.266	0.0167	363	0.0093	392
11	31.0	801	0.278	0.0167	363	0.0154	373
12	31.8	801	0.271	0.0167	363	0.0093	373

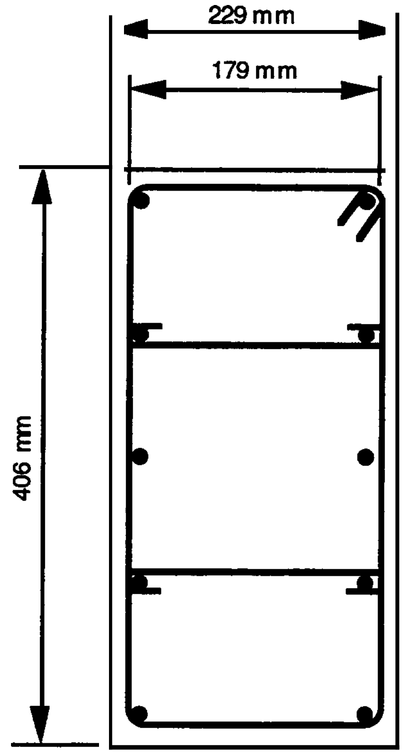
Longitudinal steel - 4 deformed bars, 22 mm diameter, grade 40
Lateral reinforcement: 9.5 mm diameter deformed bars, grade 40
* Calculated from data given in report

Half height of specimens: L = 1676mm

Data Files:
AT75N1S1.WK1
AT75N2S1.WK1
AT75N3S1.WK1
AT75N4S1.WK1
AT75N5S1.WK1
AT75N6S1.WK1
AT75N9.WK1
AT75N10.WK1
AT75N11.WK1
AT75N12.WK1

1982 Umehara and Jirsa





Specimens CUS, CUW, and XUS

Unit No.	Direction of Bending	Lateral Reinforcement	
		Bardia. mm	Spacing (ctrs.) mm
CUS	Strong	6	64
CUW	Weak	6	64
2cus	Strong.	6	64

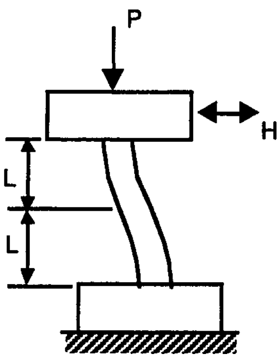
Unit No.	Concrete Strength, MPa	Axial Load kN	Axial Load / Axial Capacity*	Longitudinal Reinforcement		Transverse Reinforcement	
				ρ*	f_y MPa	ρ*	f_y MPa
CUS	34.9	534	0.165	0.0306	441	0.0028	414
CUW	34.9	534	0.165	0.0306	441	0.0031	414
2CUS	42.0	1068	0.274	0.0306	441	0.0028	414

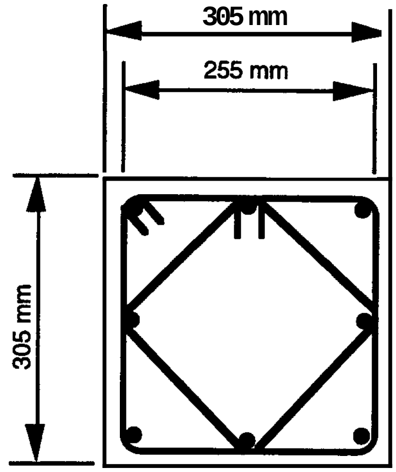
Longitudinal steel - 10 deformed bars, 19 mm diameter
Lateral reinforcement: 6 mm diameter deformed bars
* Calculated from data given in report

Half height of specimens: L = 457 mm

Data Files: UMECUS.WK1
UMECUW.WK1
UME2CUS.WK1

1985 Bett, Klingner and Jirsa





Specimen 11

Bett, Bart J.; Klingner, Richard E.; and Jirsa, James O., "Behavior of Strengthened and Repaired Reinforced Concrete Columns Under Cyclic Deformations," PMFSEL Report No. 85-3, Department of Civil Engineering, University of Texas at Austin, Austin, Texas, December 1985, 75 pages.

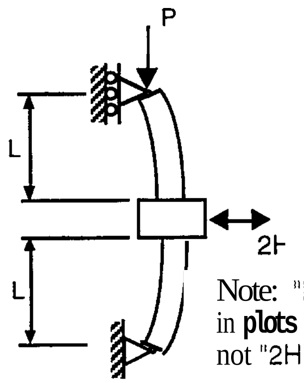
Three columns at two-thirds scale were tested. Two columns were strengthened by adding reinforced concrete jackets before testing. Results from these strengthened specimens are not reported here; only data from the one unstrengthened specimen were digitized for this report. The specimens were subjected to a constant axial load, and the ends of the specimens were restrained against rotation.

unit No.	Lateral Reinforcement	
	Bar dia. mm	spacing (ctrs.) mm
1-1	6	203

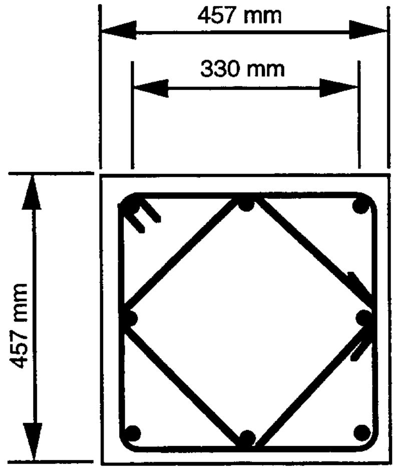
Unit No.	Concrete Strength, MPa	Axial Load kN	AxialLoad / Axial Capacity	Longitudinal Reinforcement		Transverse Reinforcement	
				ρ*	f_y MPa	ρ*	f_y MPa
1-1	29.9	288	0.104	0.0244	462	0.0026	414

Data File: BETTNO11.WK1

1988 Azizinamini, Johal, Hanson, Musser, and Corley



Note: "H" is given in plots and data files, not "2H"



Specimens NC-2 and NC-4

Azizinamini, Atorod; Johal, Lakhpal S.; Hanson, Norman W.; Musser, Donald W.; and Corley, William G., "Effects of Transverse Reinforcement on Seismic Performance of Columns - A Partial Parametric Investigation," Project No. CR-9617, Construction Technology Laboratories, Skokie, Illinois, Sept. 1988.

Twelve full-scale tests were conducted. Eleven of the specimens had a square cross section, and one had a circular cross section. The main variables studied were the level of axial load, type of transverse reinforcement, and the amount and spacing of transverse reinforcement. Digitizable load deflection plots were available for only two of the tests on columns with square cross sections. The tests were conducted using a double-ended specimen, a self-reacting load frame with a hydraulic ram to apply cyclic lateral load, and a universal testing machine to apply constant axial load.

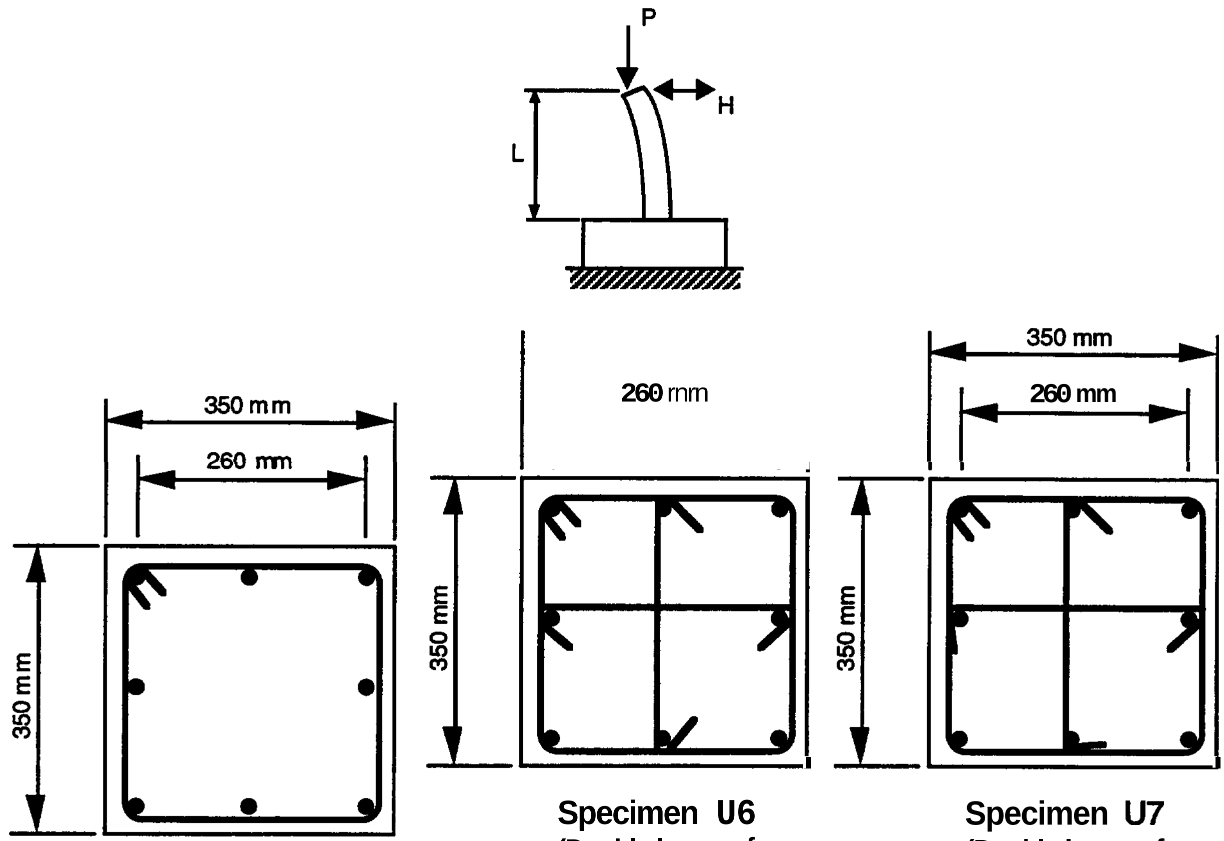
Unit No.	Lateral Reinforcement	
	Bardia. mm	Spacing (ctrs.) mm
NC-2	12.7	102
NC-4	9.5	102

Unit No.	Concrete Strength, MPa	Axial Load kN	Axial Load / Axial Capacity*	Longitudinal Reinforcement		Transverse Reinforcement	
				ρ	f_y MPa	ρ	f_y MPa
NC-2	39.3	1690	0.206	0.0195	439	0.0219	454
NC-4	39.8	2580	0.310	0.0195	439	0.0126	616

Half height of specimen: L = 1372 mm

Data Files: AZI88NC2.WK1
AZI88NC4.WK1

1989 Saatcioglu and Ozcebe



Specimens U3 and U4

Specimen U6
(Double layers of hoops and ties)

Specimen U7
(Double layers of hoops and ties)

Saatcioglu, Murat; and Ozcebe, Guney, "Response of Reinforced Concrete Columns to Simulated Seismic Loading," American Concrete Institute, ***ACI Structural Journal,*** January-February, 1989, pp. 3-12.

The authors conducted a series of tests on 14 cantilever column specimens. The columns cross section was square, and three different lateral reinforcement configurations were tested. The main variables investigated were axial load, confining reinforcement, and deformation path. Of the fourteen specimens, seven had lateral displacements applied along a principal axis of the cross section ("U" series); four had lateral displacements applied along a diagonal of the cross section ("D" series); and two had bidirectional lateral displacement patterns ("B" series). Only certain specimens from the "U" series are presented here. Of the "U" series specimens, U1 had no axial load applied, and U5 had variable axial load, so results for U1 and U5 are not presented. Lateral load vs. lateral displacement data files were obtained directly from the researchers who performed the tests. The data file for specimen U2 was not readable, so data for U2 is not presented.

Unit No.	Lateral Reinforcement	
	Bar dia. mm	Spacing (ctrs.) mm
U3	10	75
u 4	10	50
U6	6.4	65
U7	6.4	65

Unit No.	Concrete Strength, MPa	Axial Load kN	Axial Load / Axial Capacity*	Longitudinal Reinforcement		Transverse Reinforcement	
				ρ	f_y MPa	ρ	f_y MPa
U3	34.8	600	0.141	0.0327	430	1.69	470
U4	32.0	600	0.153	0.0327	438	2.54	470
U6	37.3	600	0.131	0.0327	437	1.95	425
U7	39.0	600	0.126	0.0327	437	1.95	425

Longitudinal steel - 8 deformed bars, 25 mm dia

* Calculated from data given in report

Height of specimens: L=1000 mm

Data Files: SAATU3.WK1
SAATU4.WK1
SAATU6.WK1
SAATU7.WK1

Chapter 3: Plots of Digitized Lateral Load-Lateral Deflection Data

This chapter contains plots of digital load-deflection test data for the **93** specimens described in this report. Each plot is identified by the test name shown in the upper left comer of the figure. Note that for double-ended specimens (Figure ***2,*** page 3), the force shown in the plot is one-half the force applied at the center stub of the specimen; and for double curvature specimens (Figure **3,** page **3)** the displacement shown in the plot is one-half the relative displacement between the two end beams of the specimen.

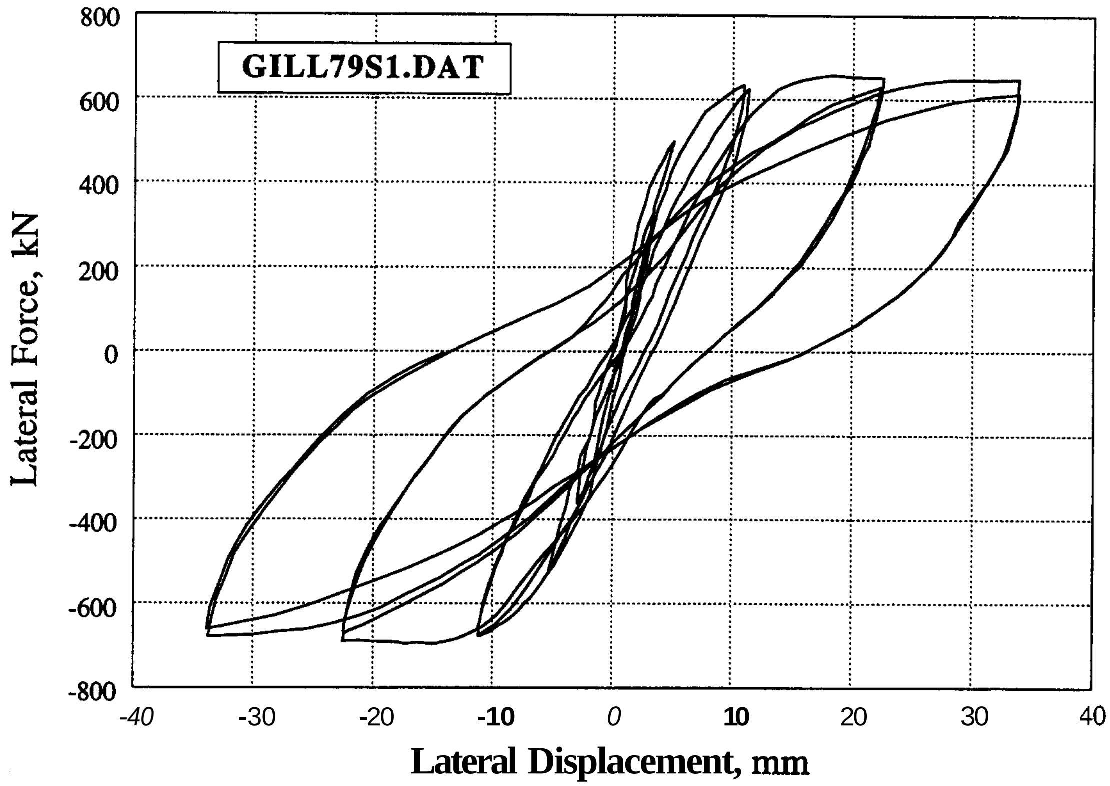


Figure 1. Specimen 1 of Gill 1979

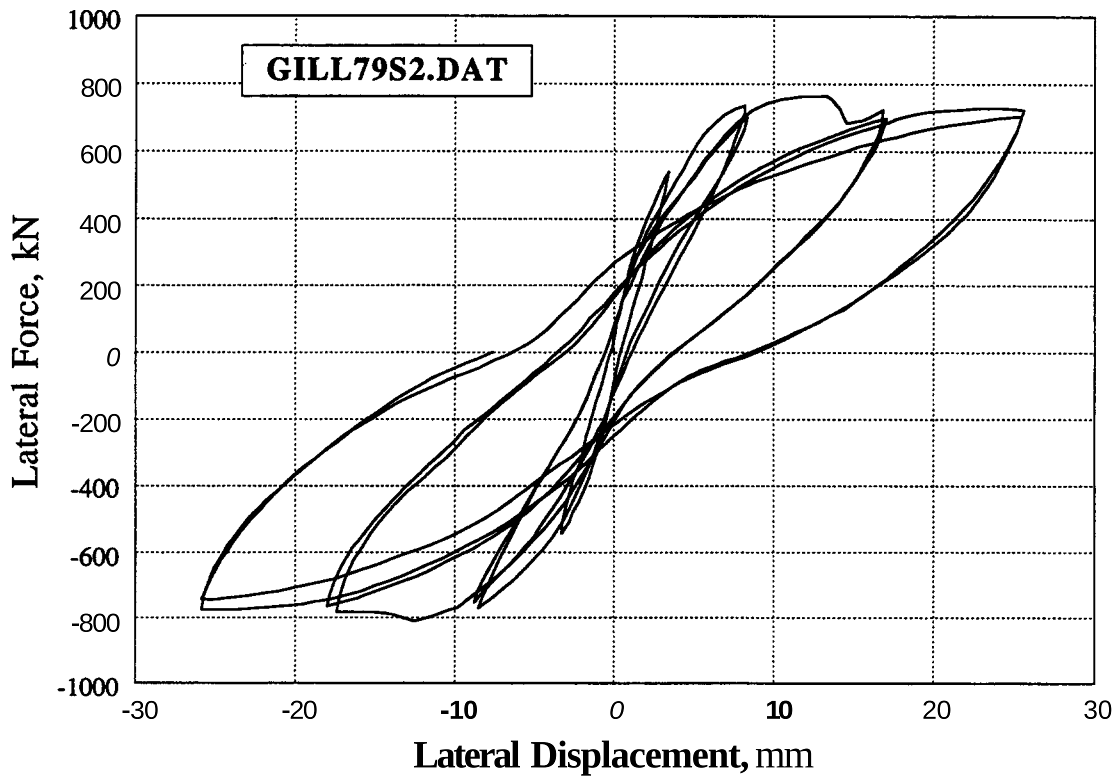


Figure 2. Specimen 2 of Gill 1979

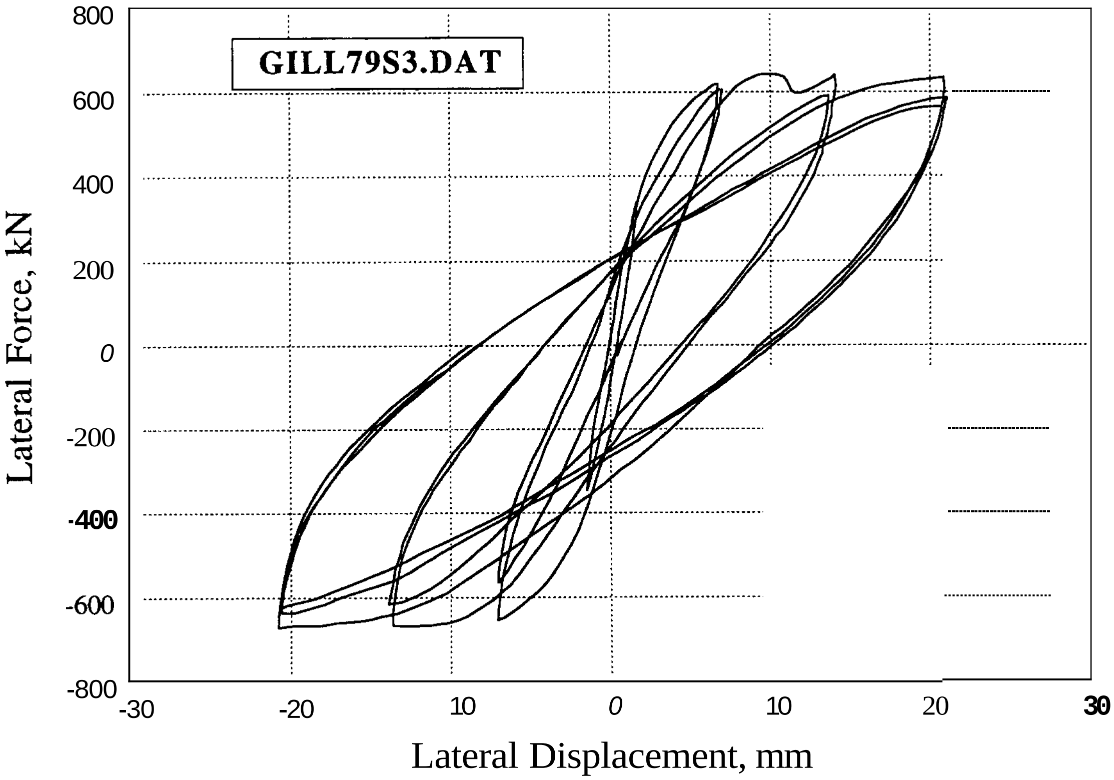


Figure 3. Specimen **3** of Gill 1979

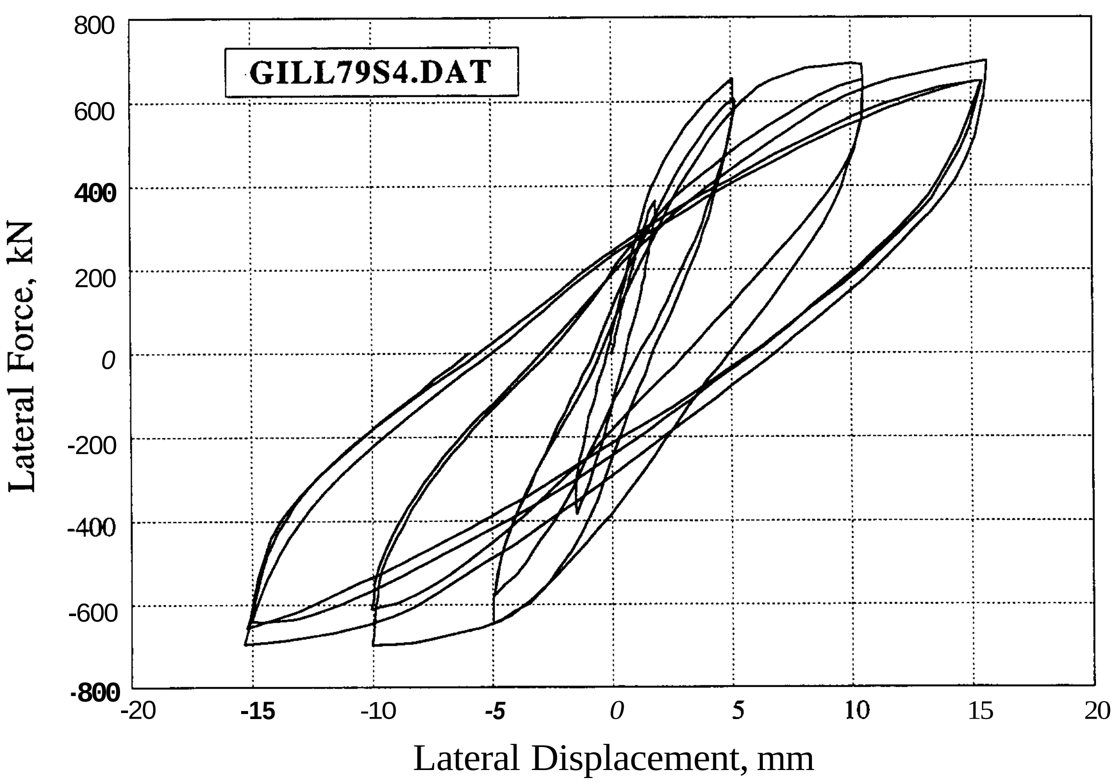


Figure **4.** Specimen **4 of** Gill 1979

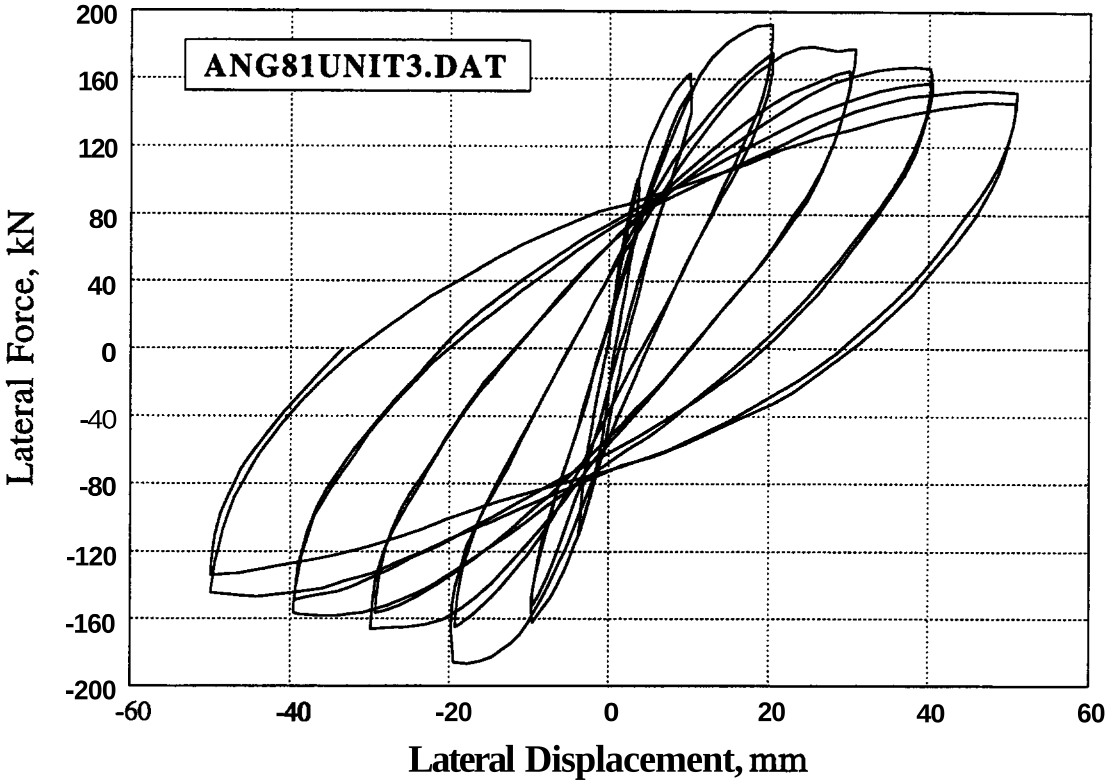


Figure 5. Specimen 3 of *Ang* 1981

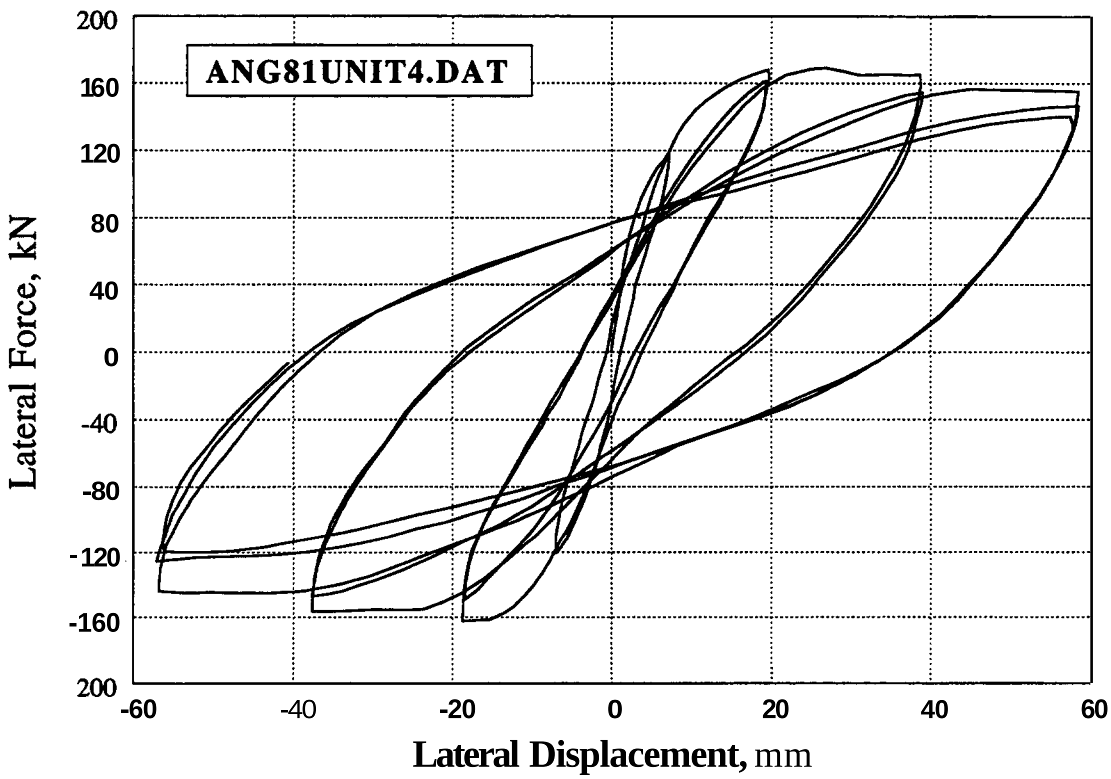


Figure 6. Specimen 4 of *Ang* 1981

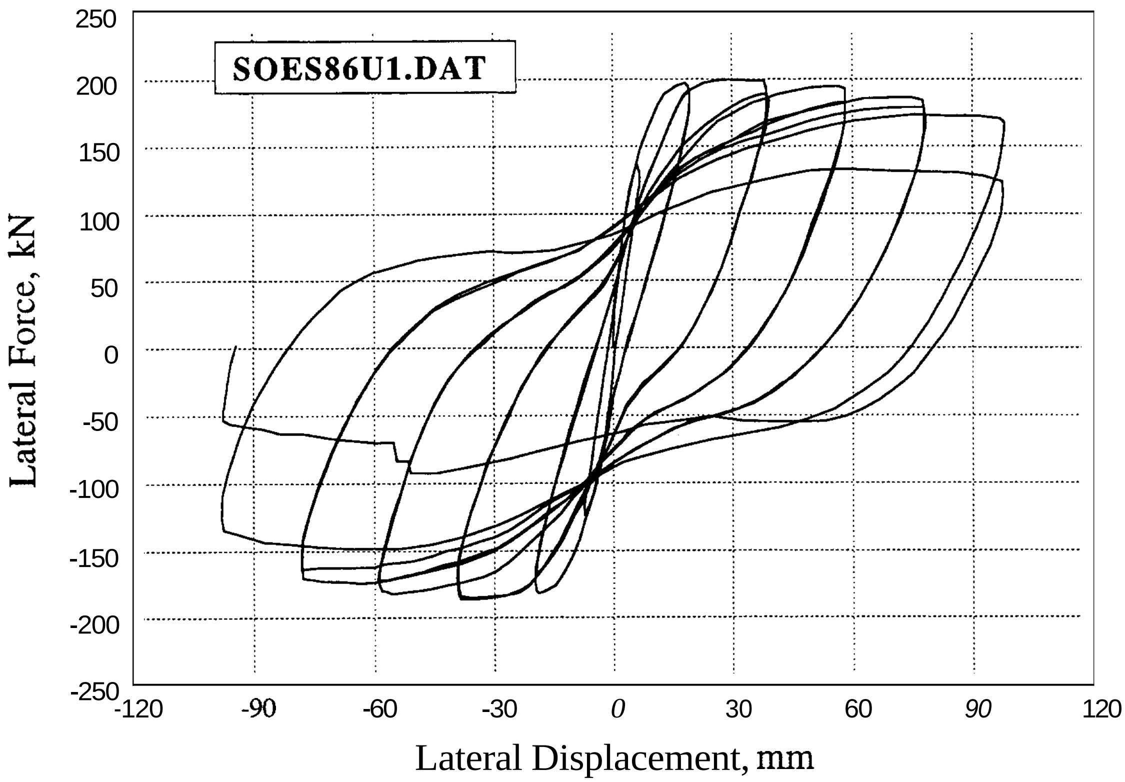


Figure 7. Specimen 1 of Soesianawati 1986

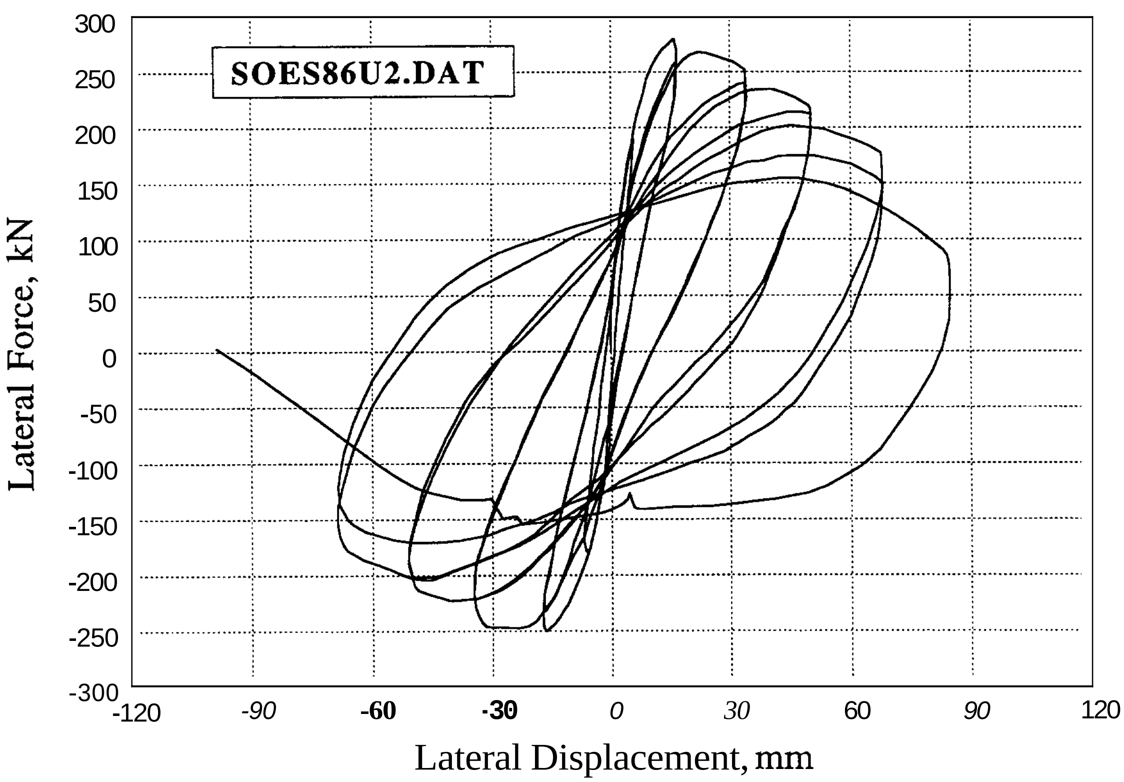


Figure **8.** Specimen 2 of Soesianawati 1986

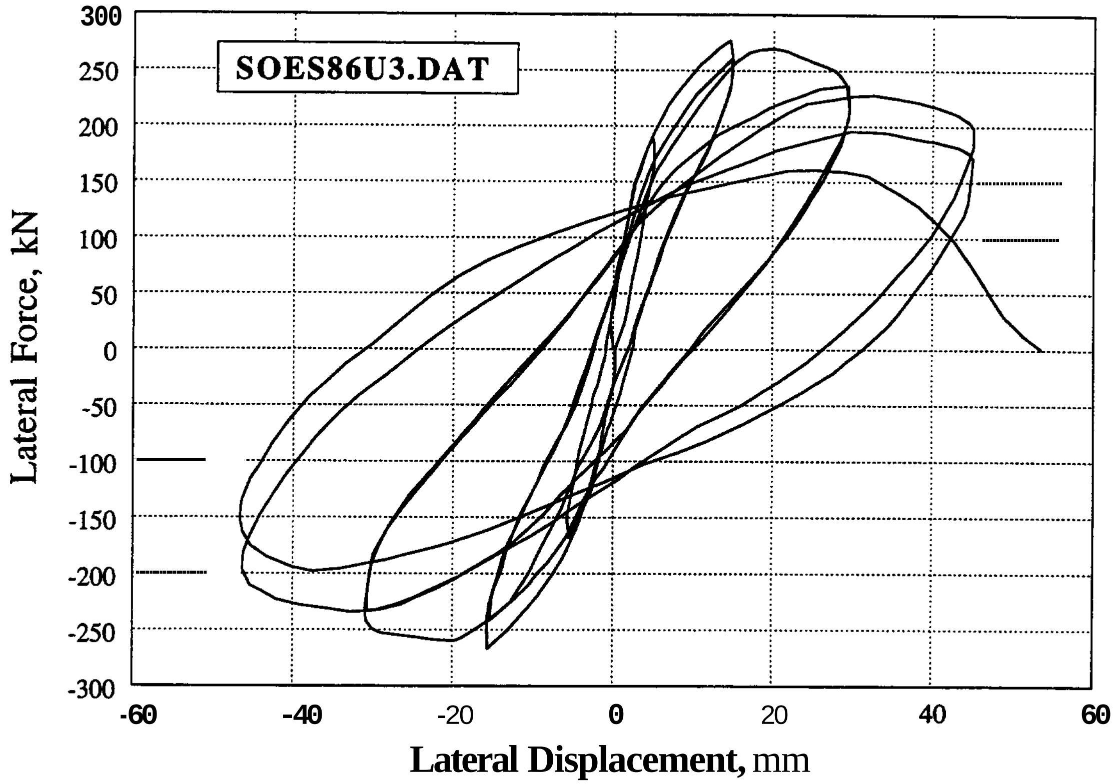


Figure 9. Specimen 3 of Soesianawati 1986

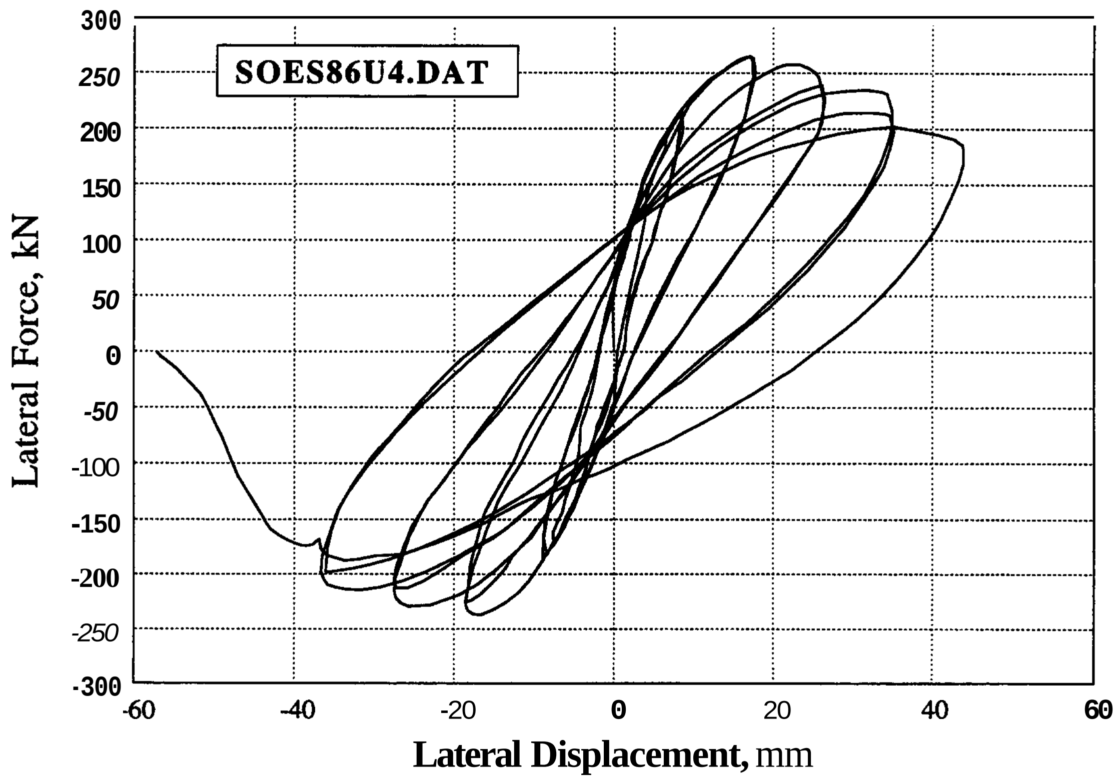


Figure 10. Specimen 4 of Soesianawati 1986

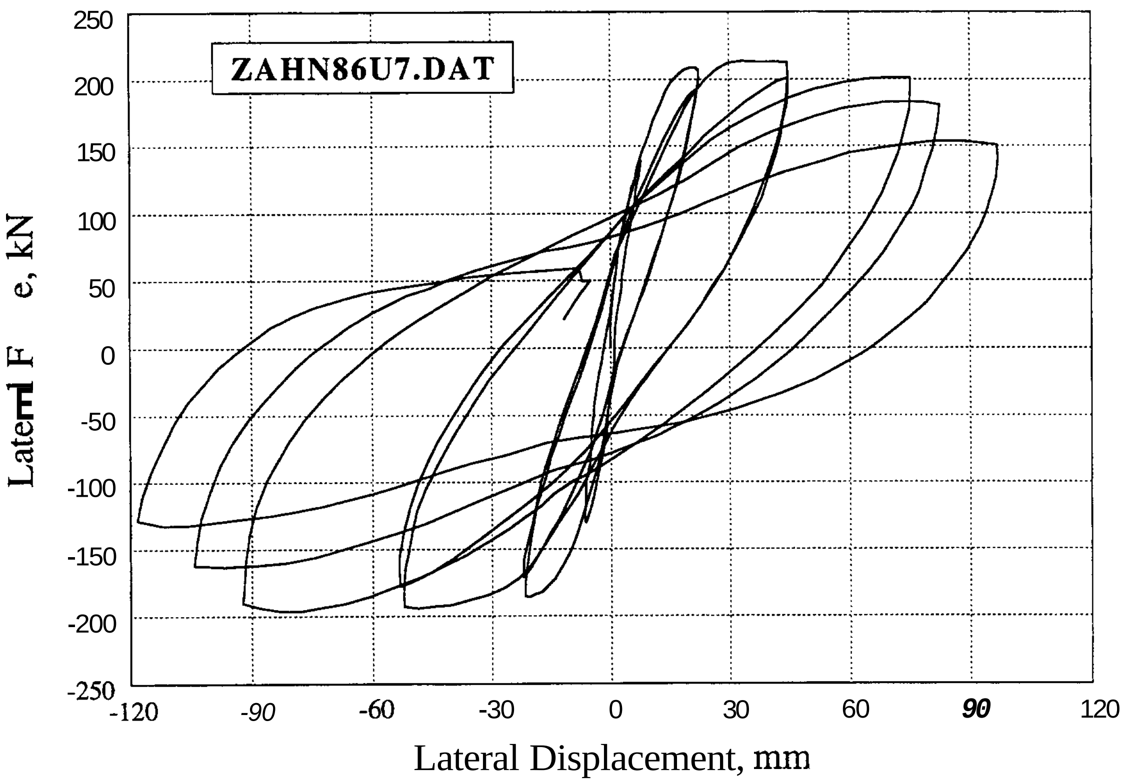


Figure 11. Specimen 7 of Zahn 1986

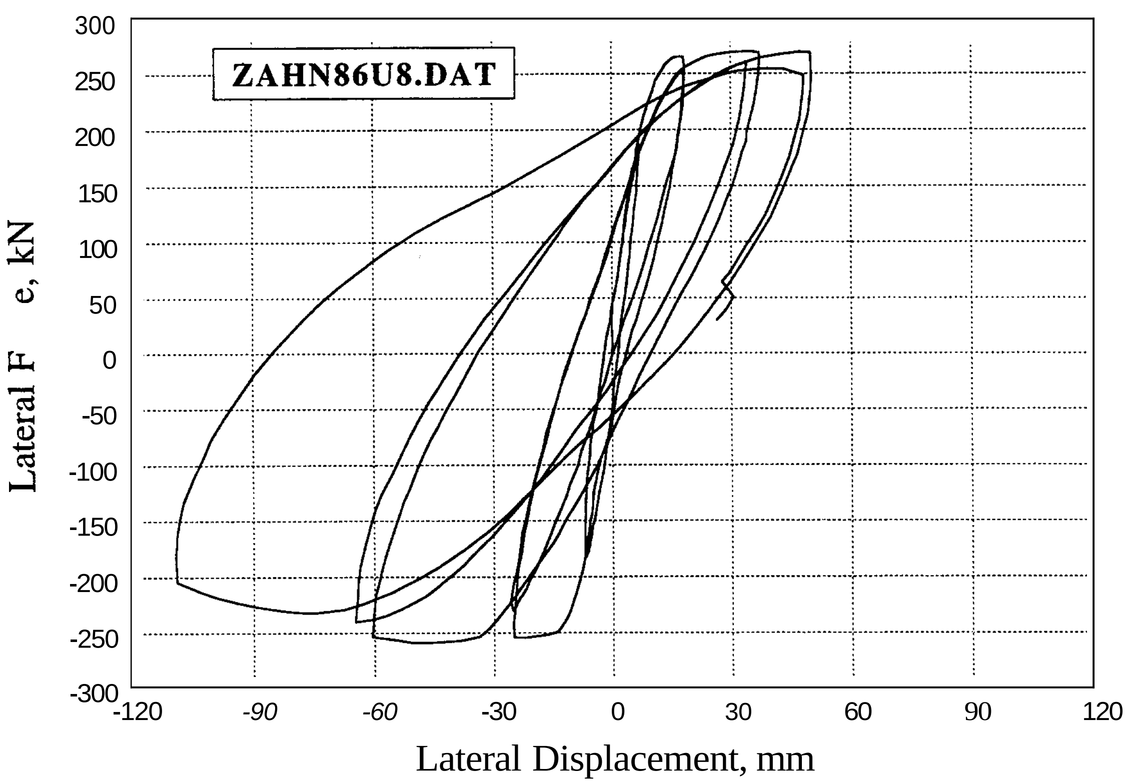


Figure 12. Specimen 8 of Zahn 1986

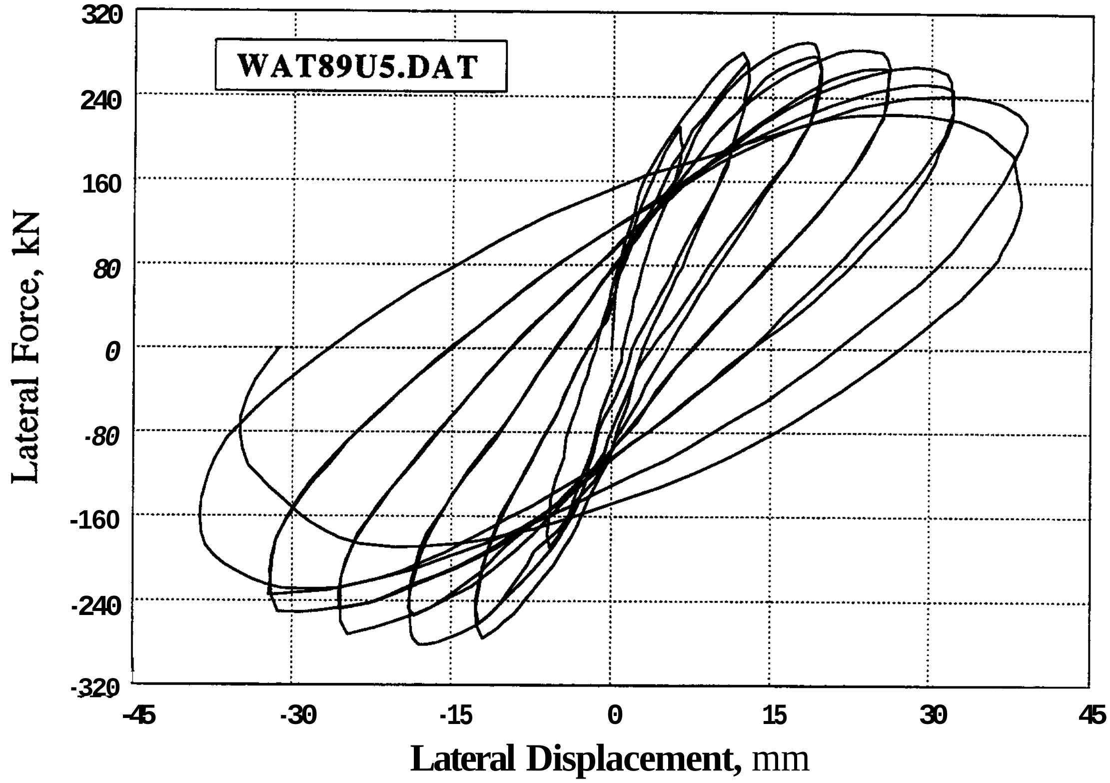


Figure 13. Specimen 5 of Watson 1989

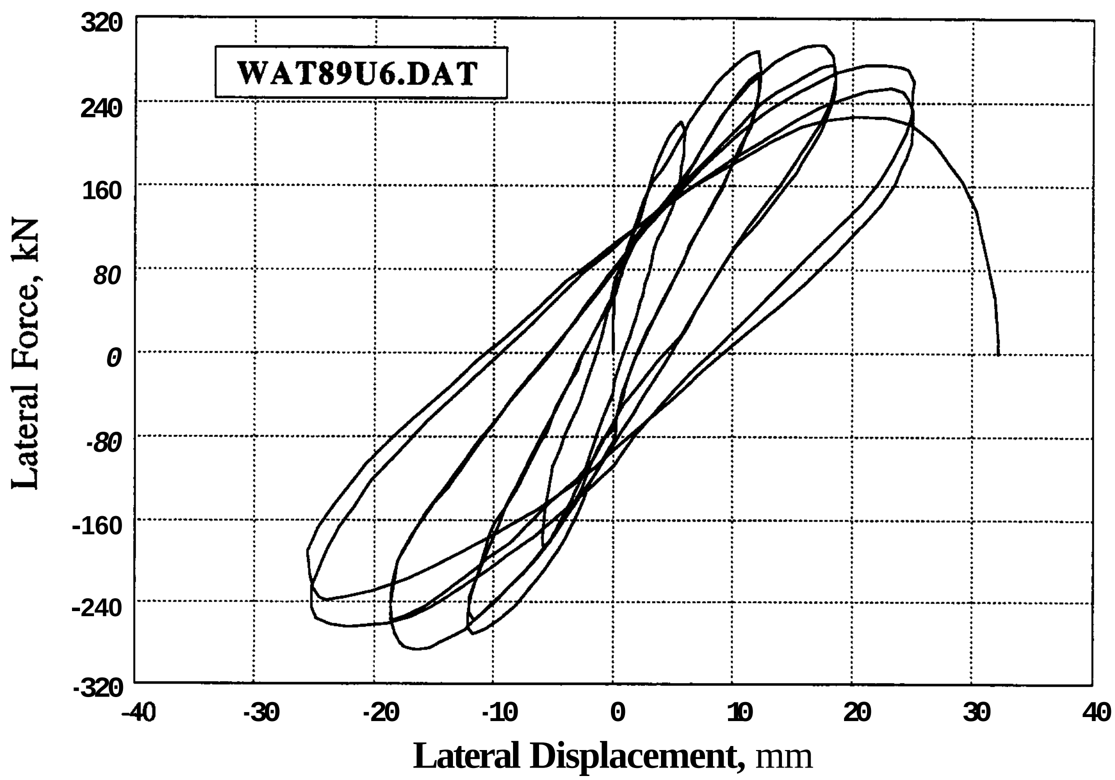


Figure 14. Specimen 6 of Watson 1989

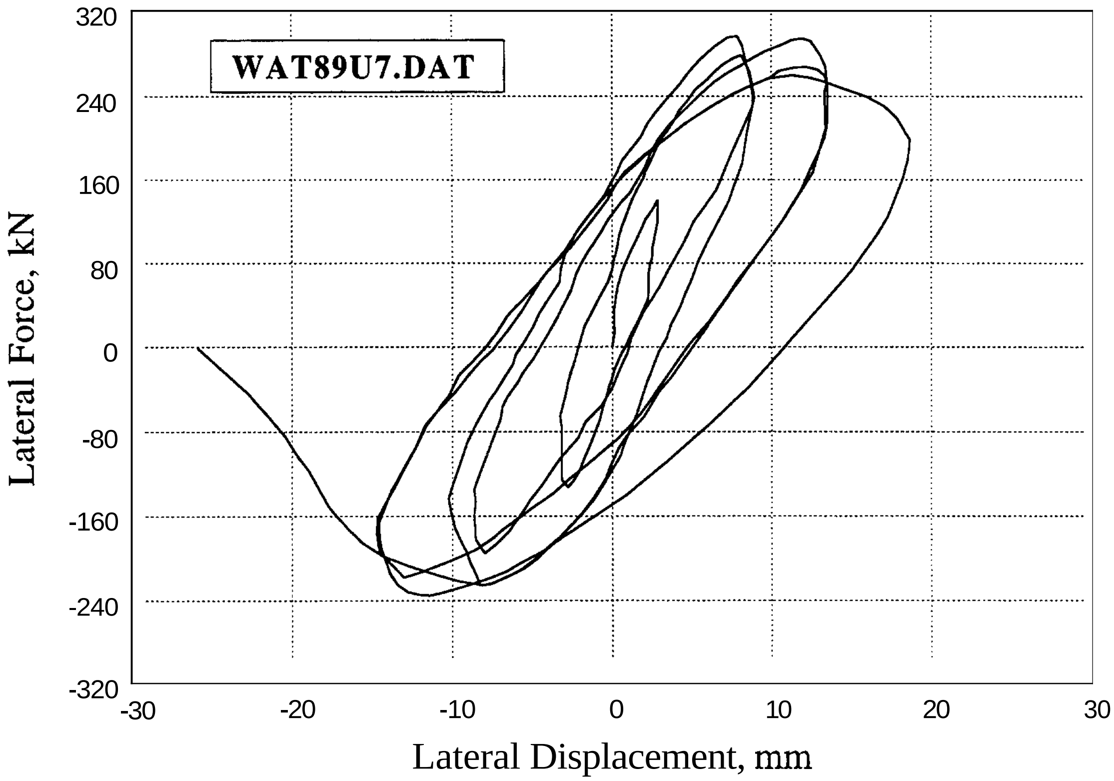


Figure 15. Specimen 7 of Watson 1989

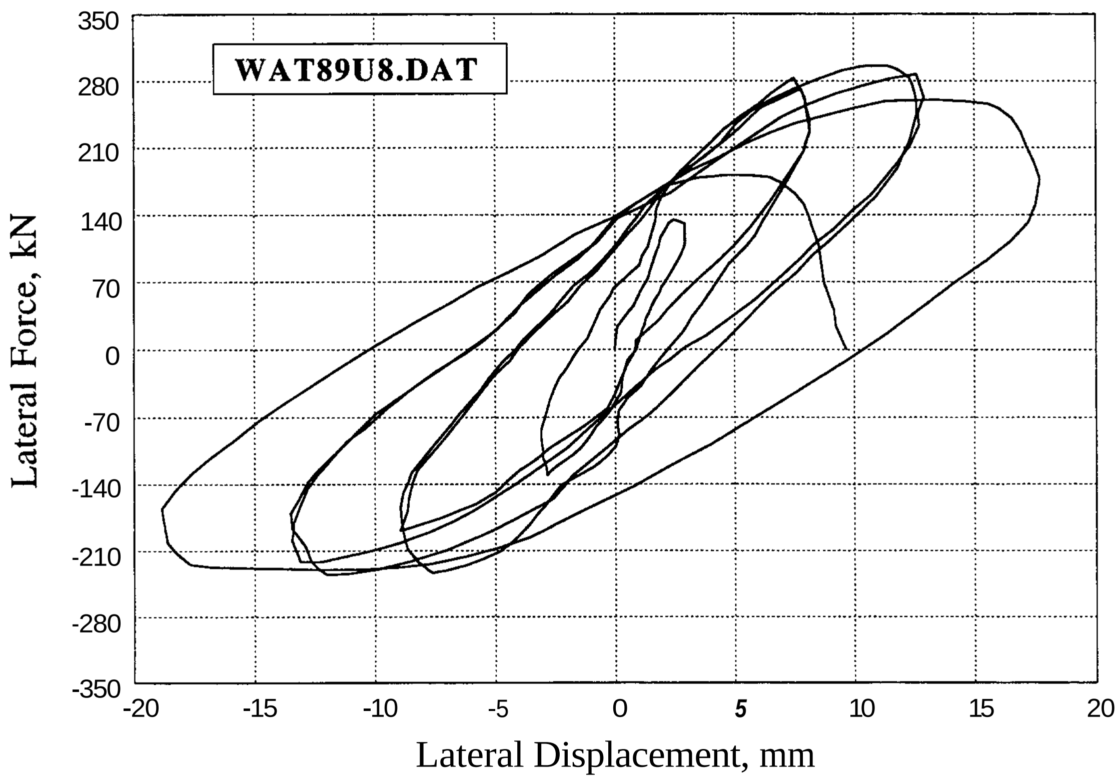


Figure 16. Specimen 8 of Watson 1989

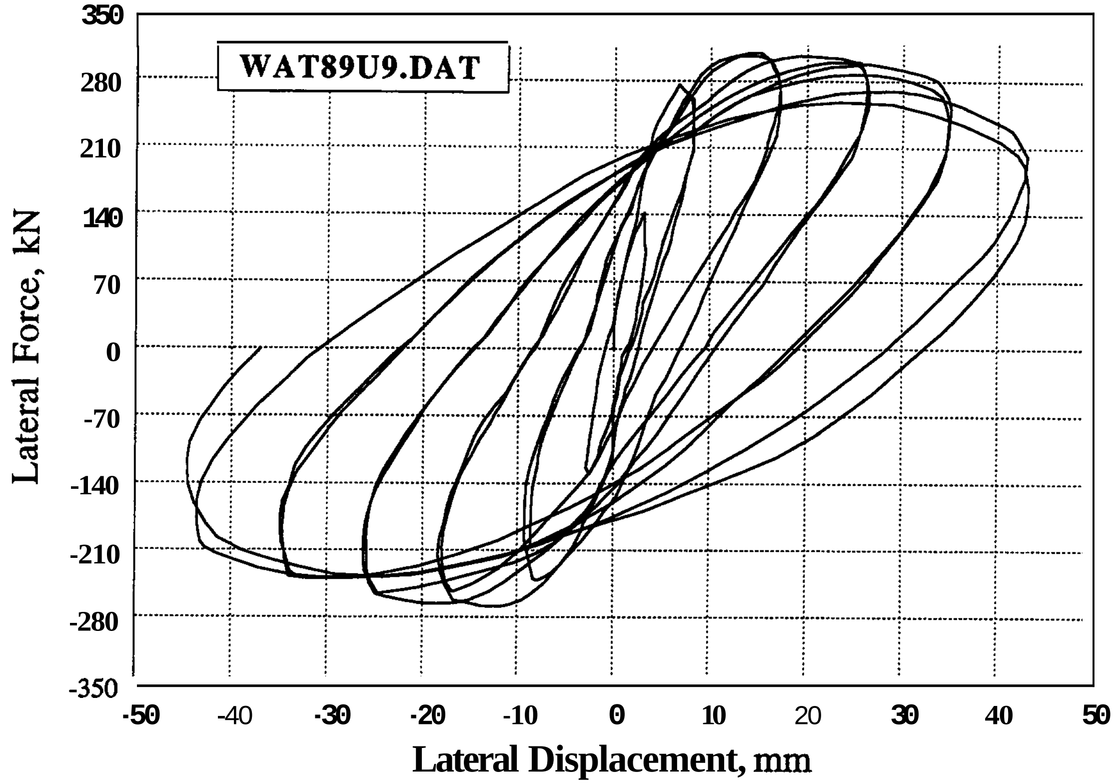


Figure 17. Specimen 9 of Watson 1989

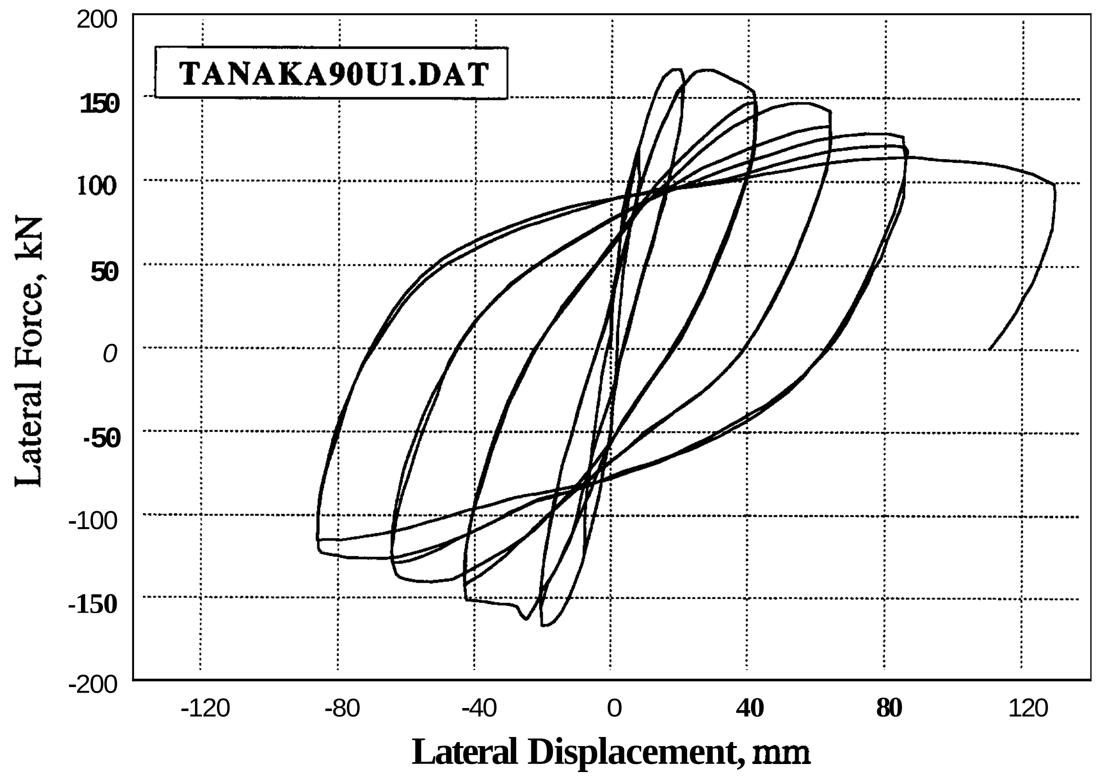


Figure 18. Specimen 1 of Tanaka 1990

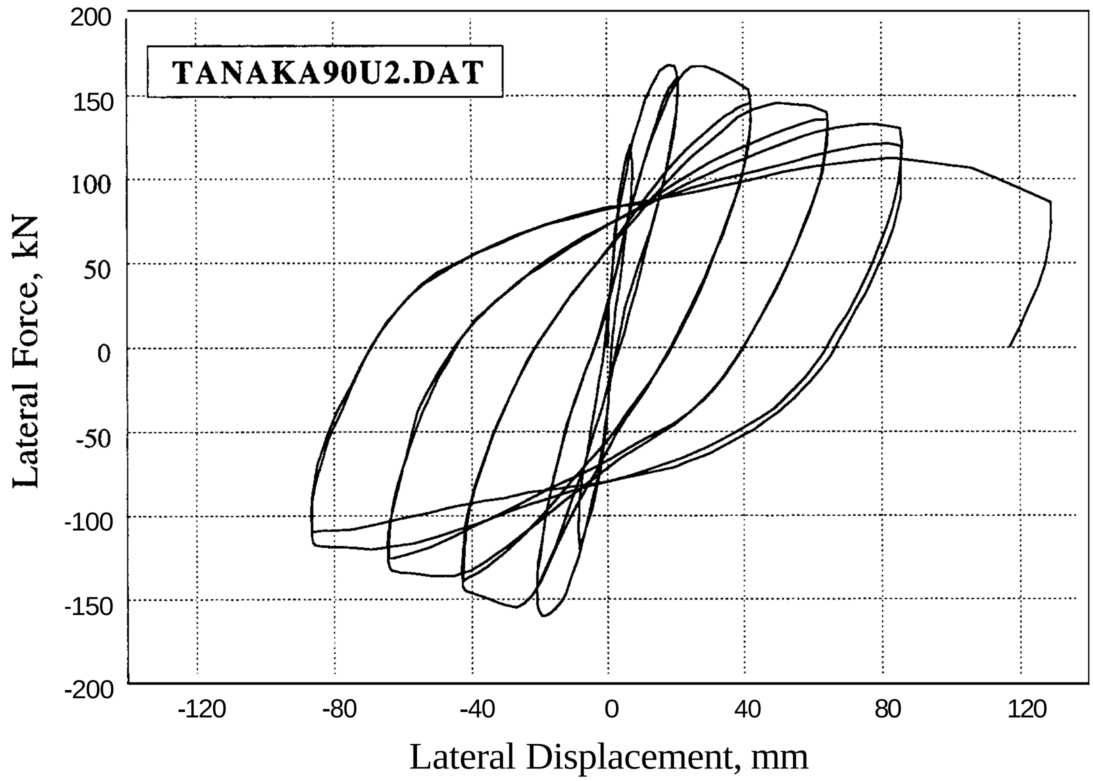


Figure 19. Specimen 2 of **Tanaka** 1990

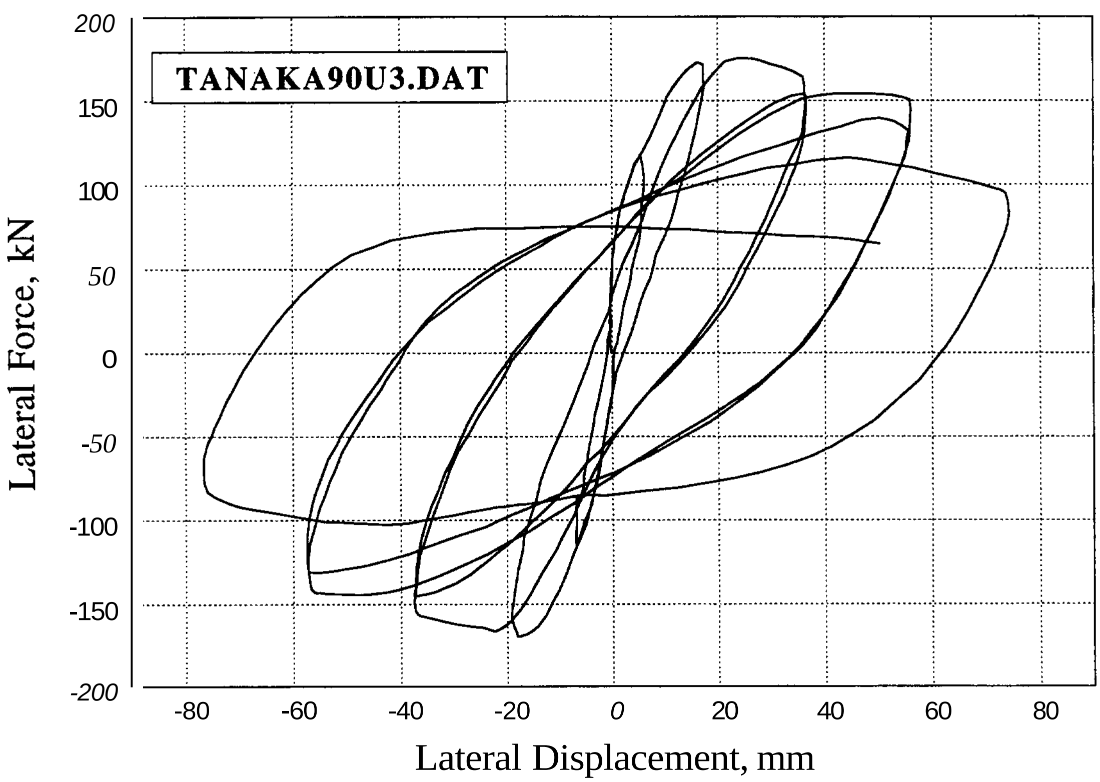


Figure 20. Specimen 3 of Tanaka 1990

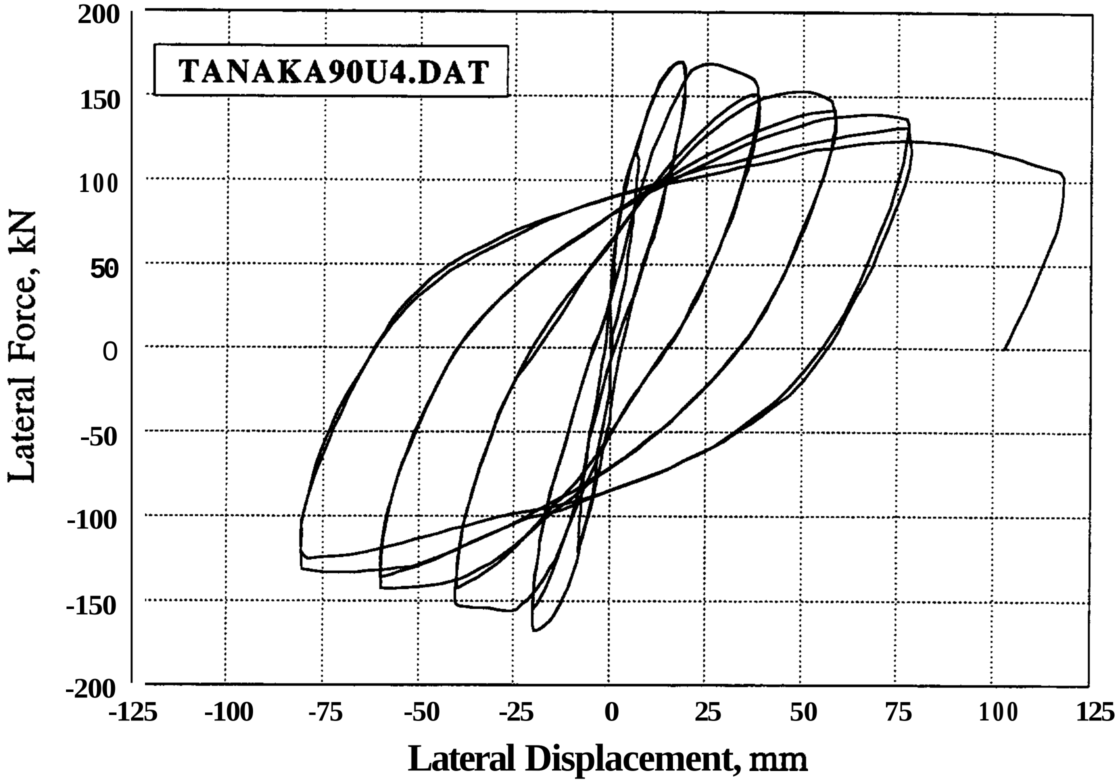


Figure 21. Specimen 4 of Tanaka **1990**

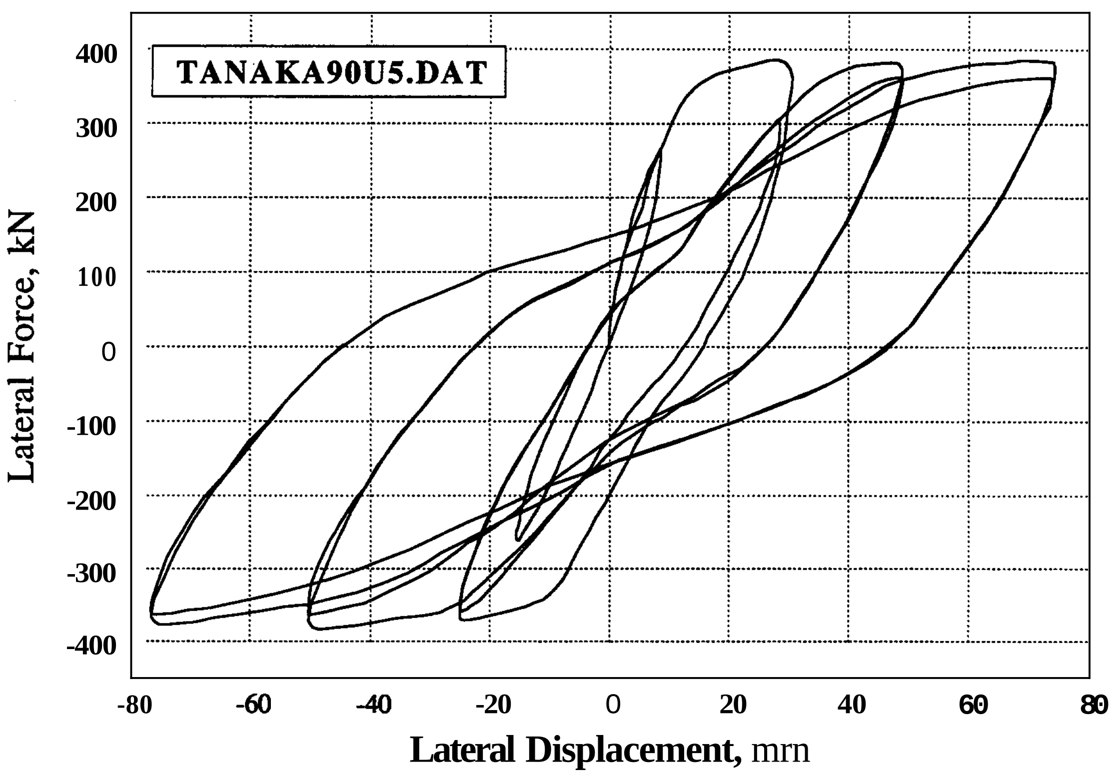


Figure 22. Specimen 5 of Tanaka 1990

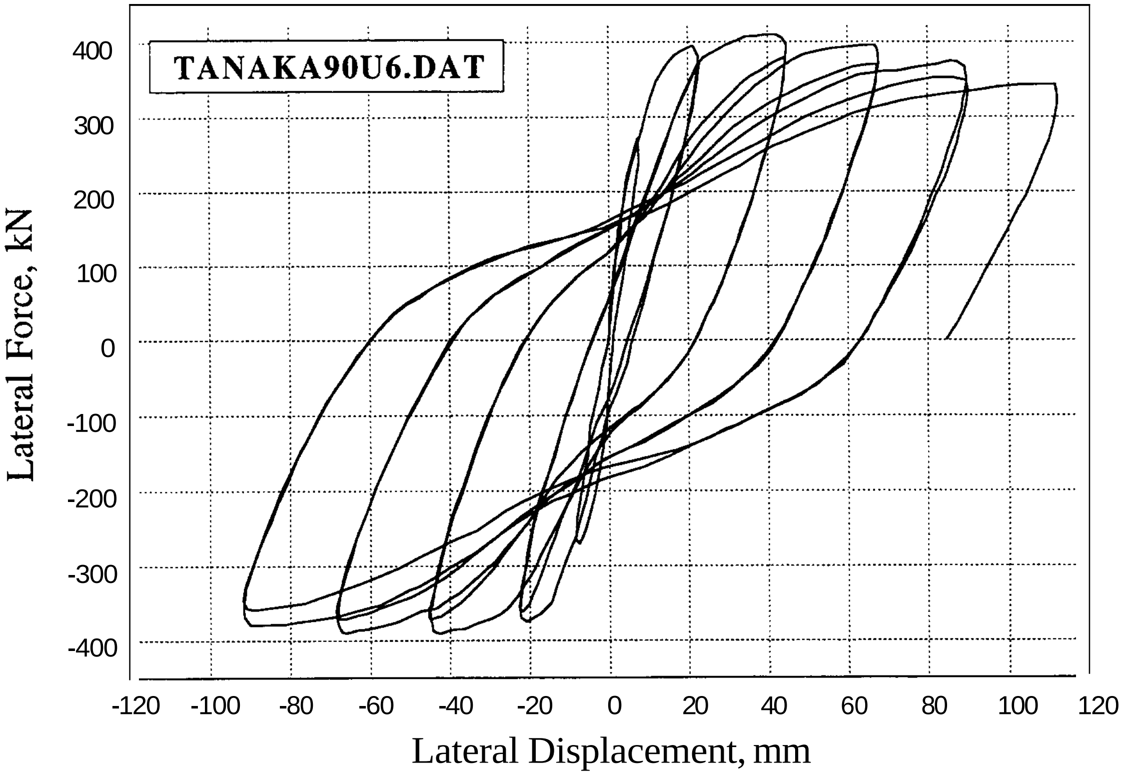


Figure 23. Specimen 6 **of Tanaka** 1990

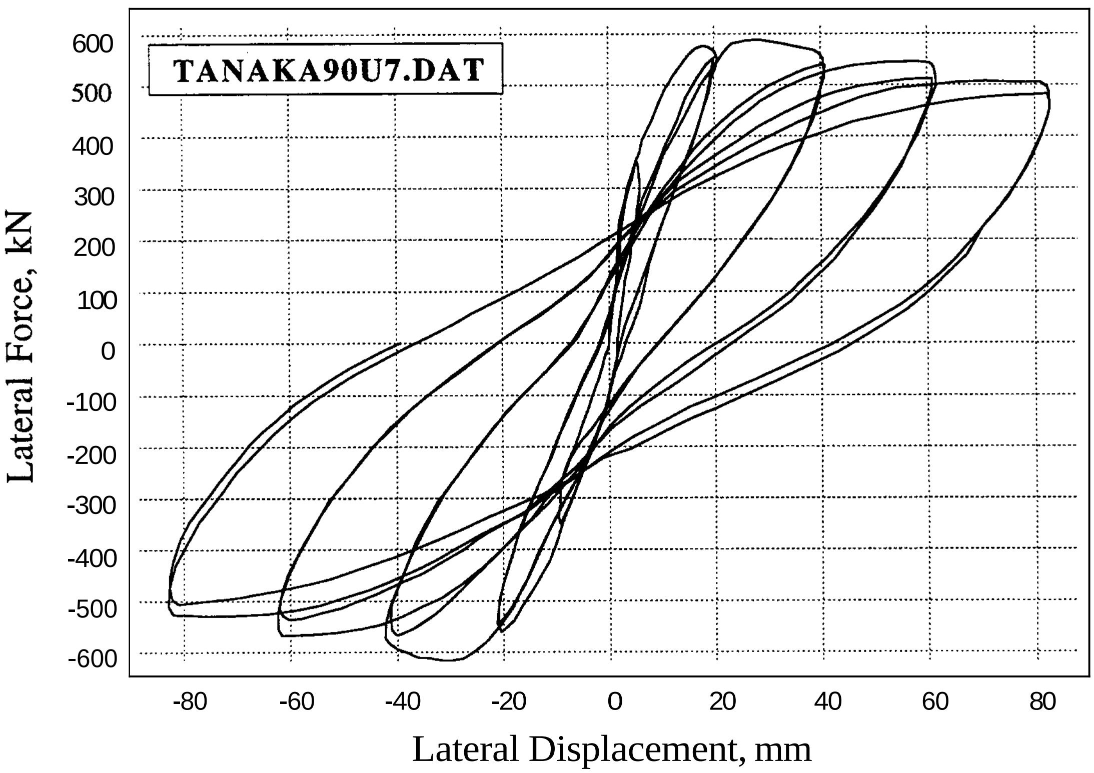


Figure **24.** Specimen 7 **of Tanaka** 1990

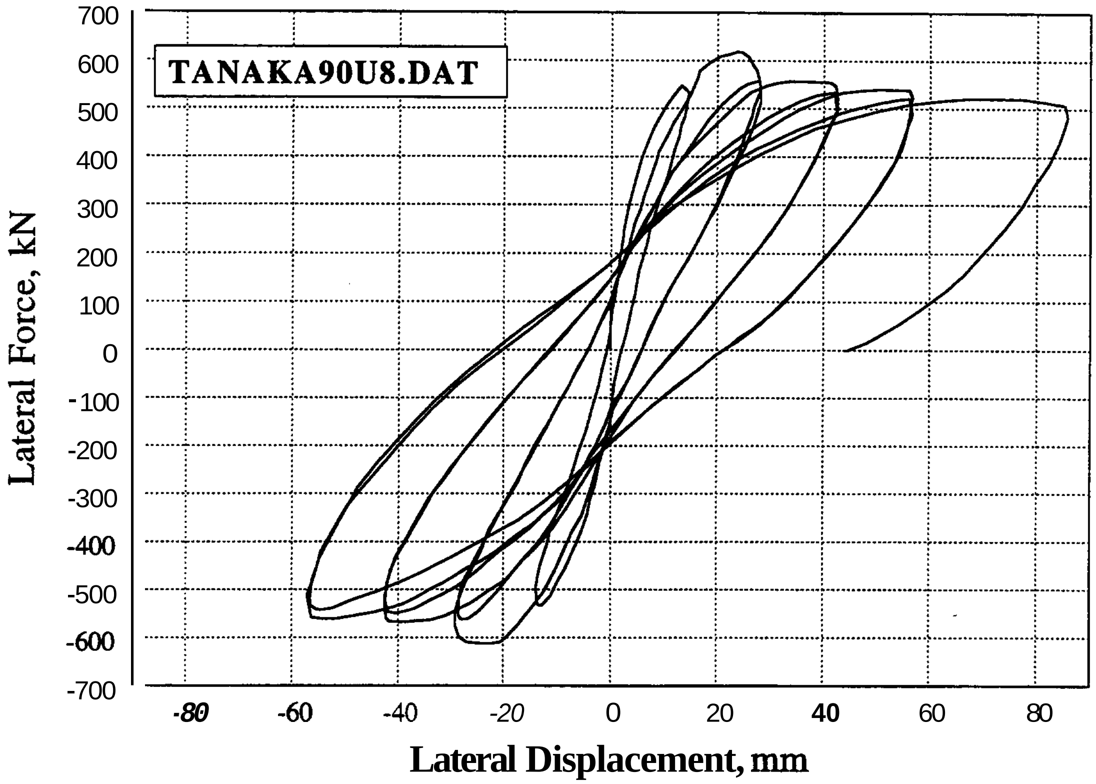


Figure 25. Specimen 8 of Tanaka 1990

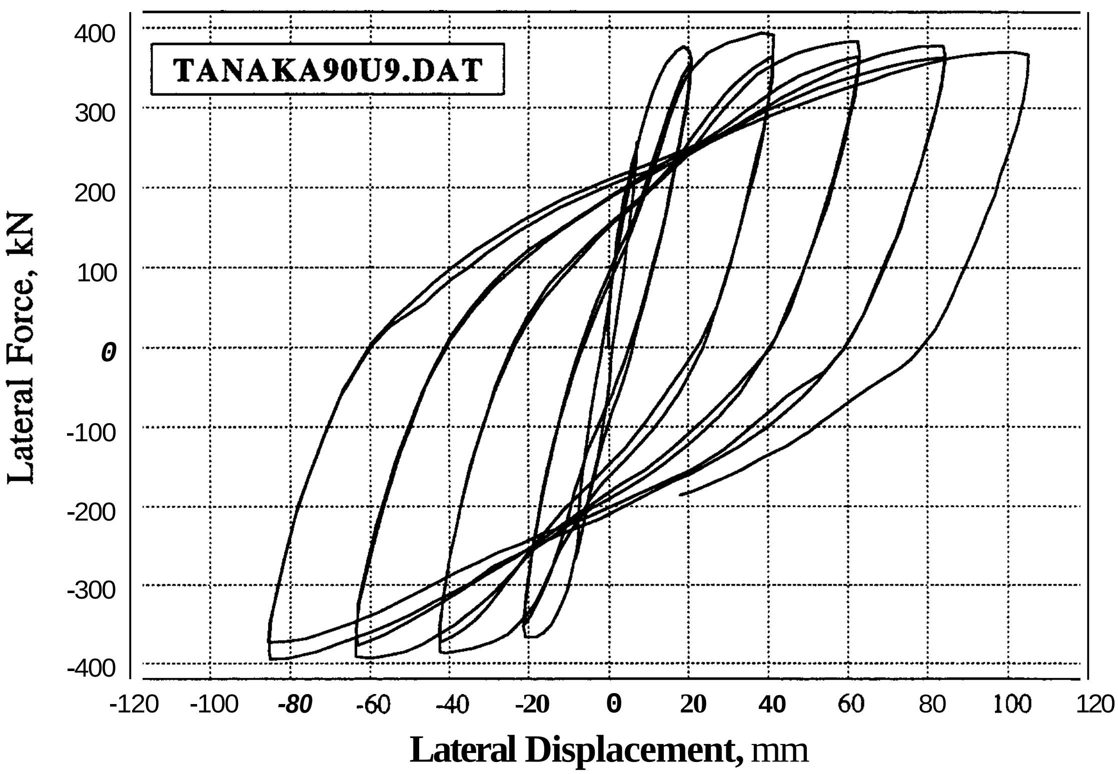


Figure 26. Specimen 9 of Tanaka 1990

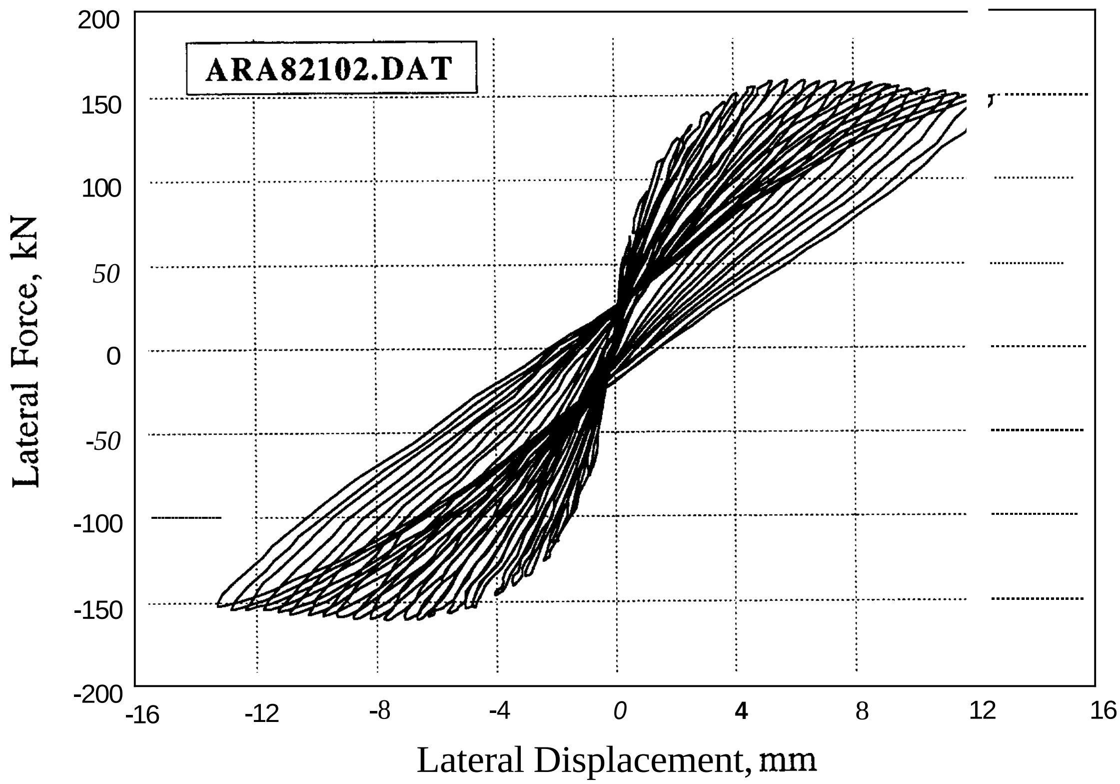


Figure 27. Specimen 102 of Arakawa 1982

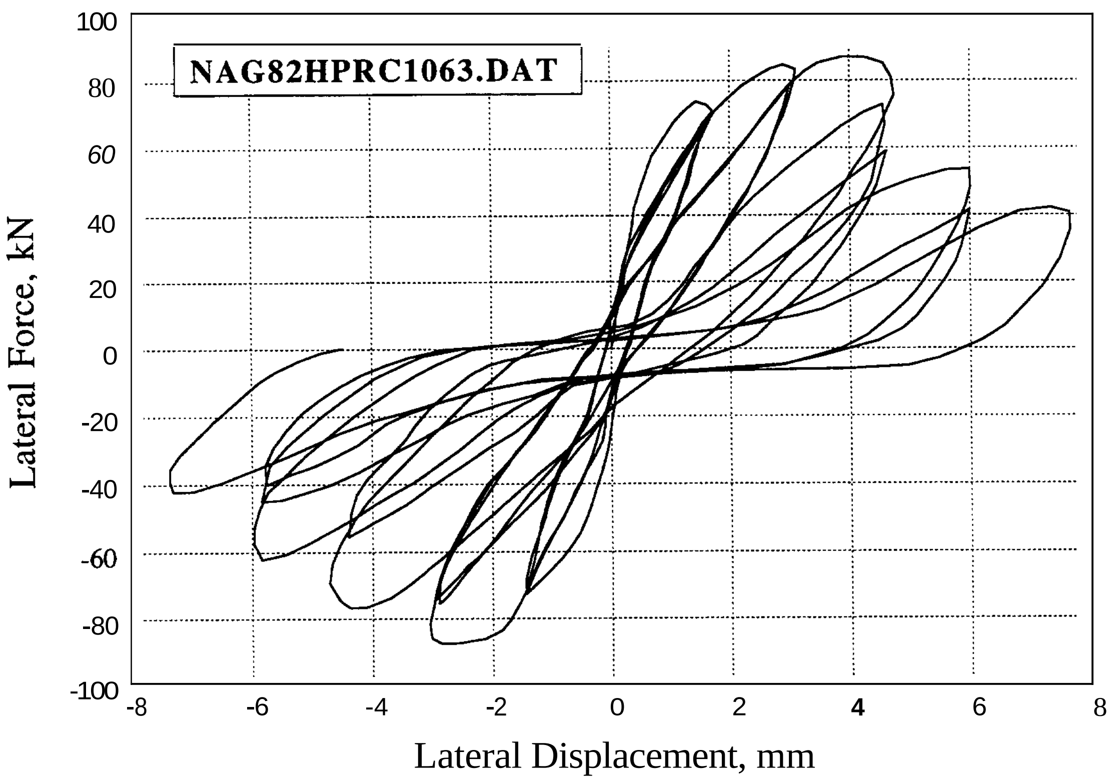


Figure 28. Specimen HPRC 10-63 of Nagasaka 1982

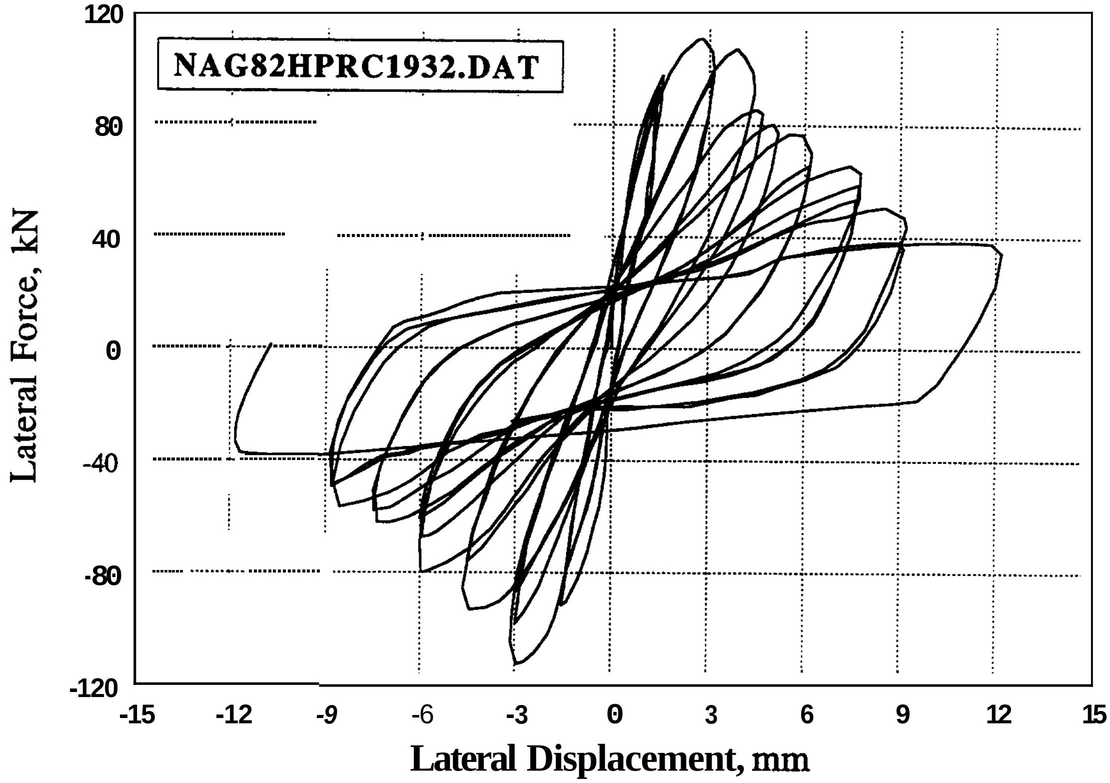


Figure 29. Specimen HPRC 19-32 of Nagasaka 1982

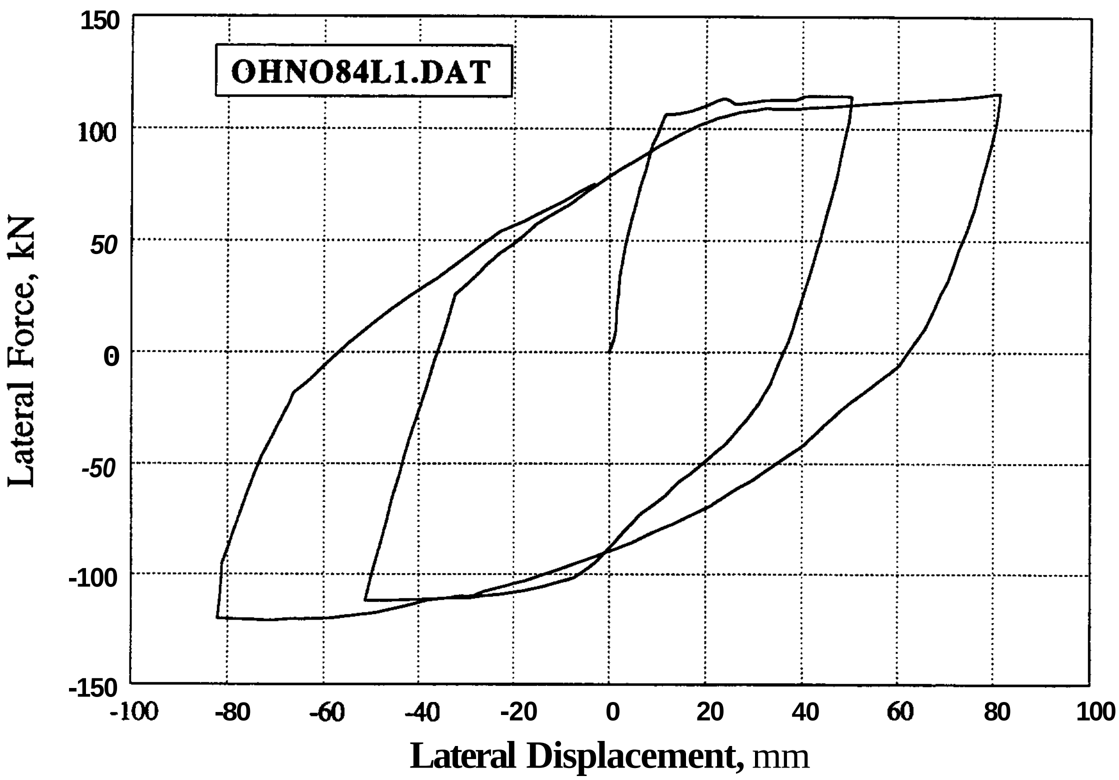


Figure 30. Specimen L1 of Ohno 1984

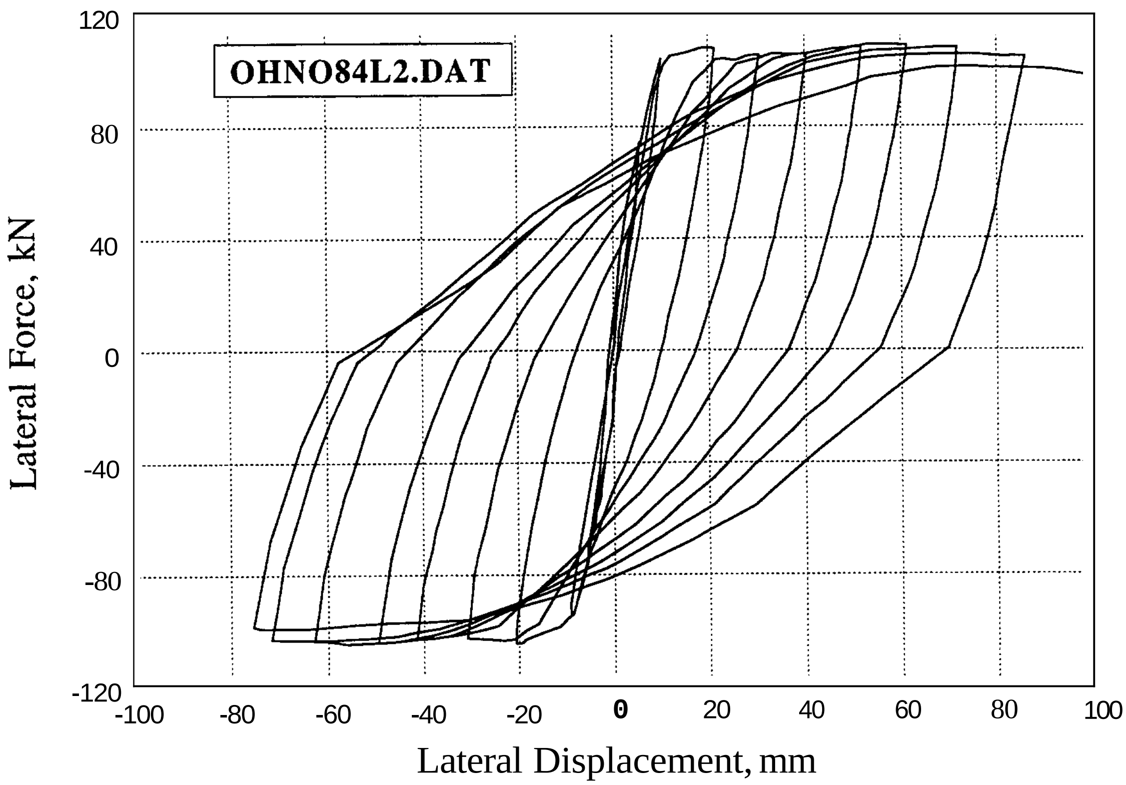


Figure 31. Specimen L2 of Ohno 1984

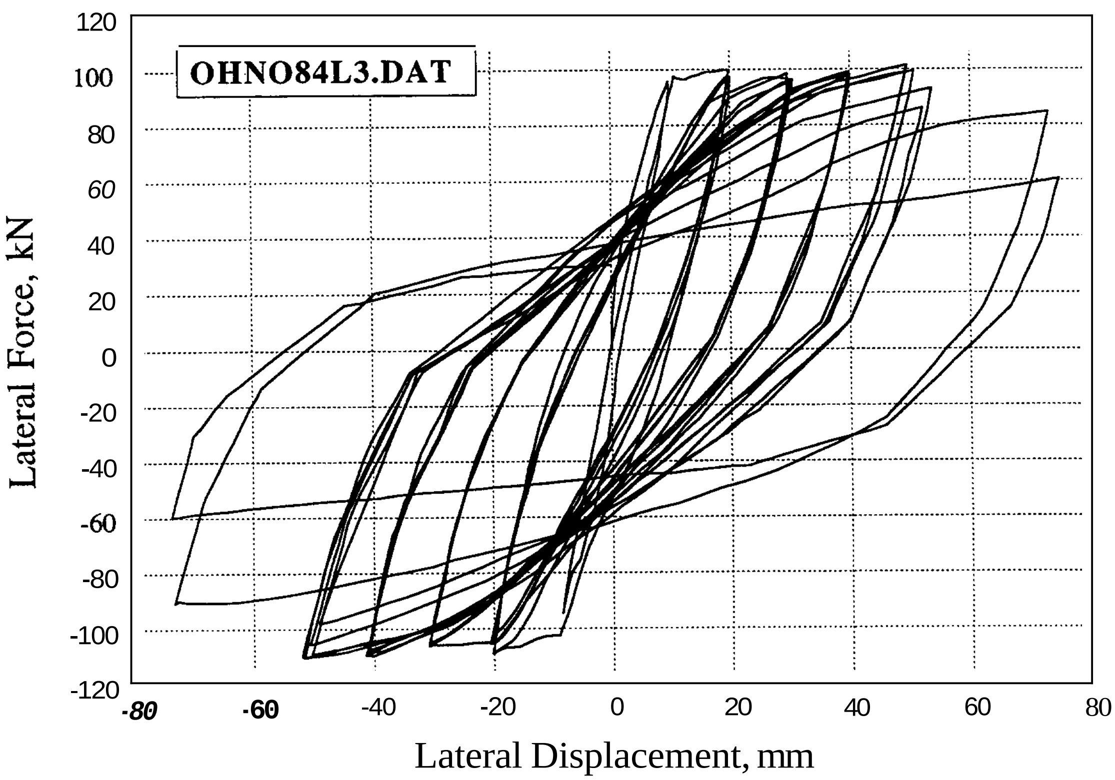


Figure 32. Suecimen L3 of Ohno 1984

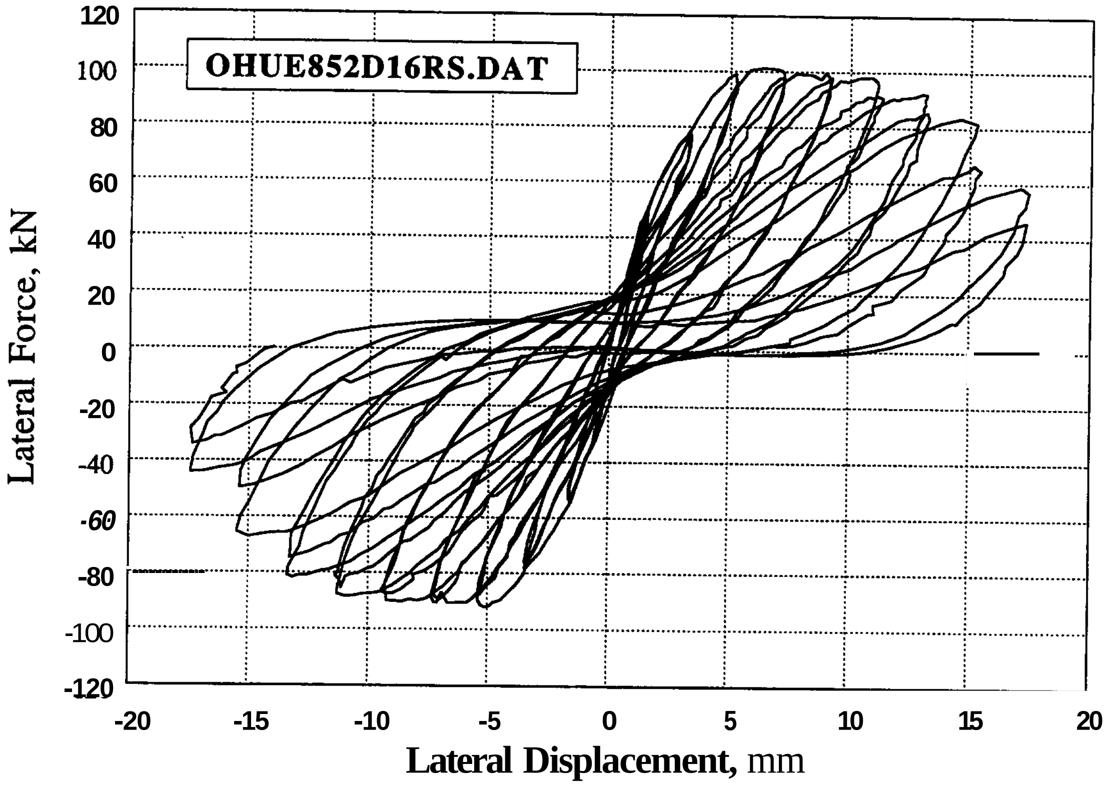
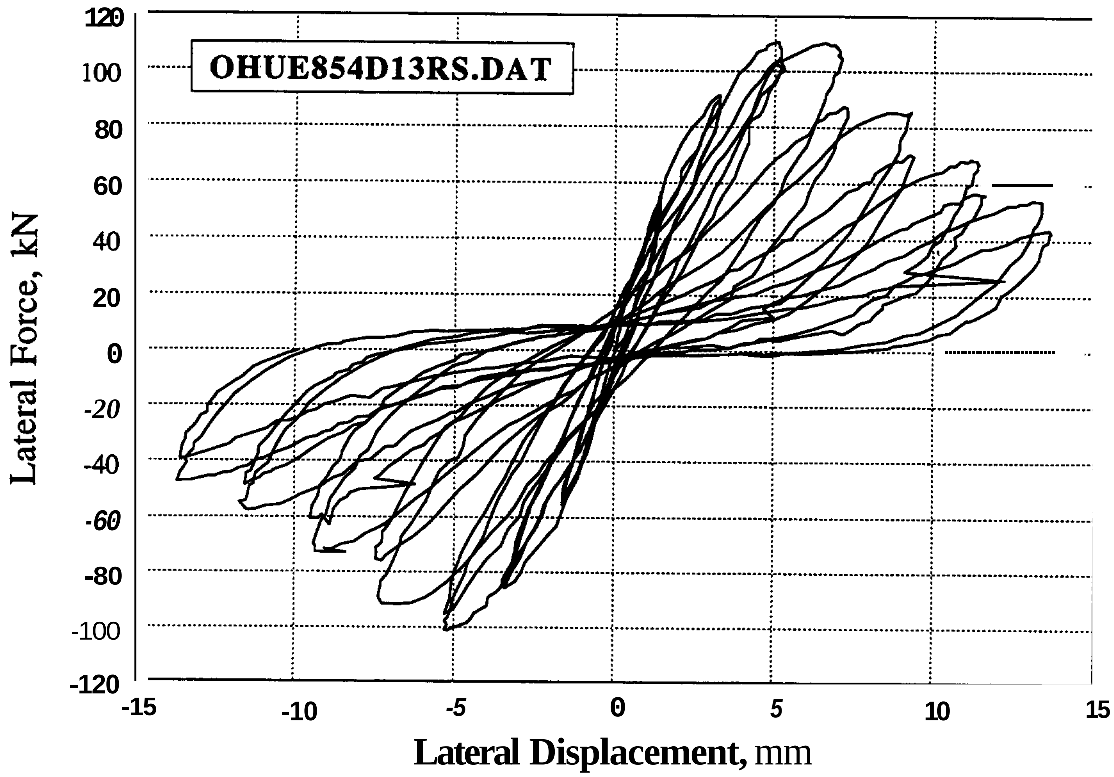


Figure 33. Specimen 2D16RS of Ohue 1985



F

Figure 34. Specimen 4D13RS of Ohue 1985

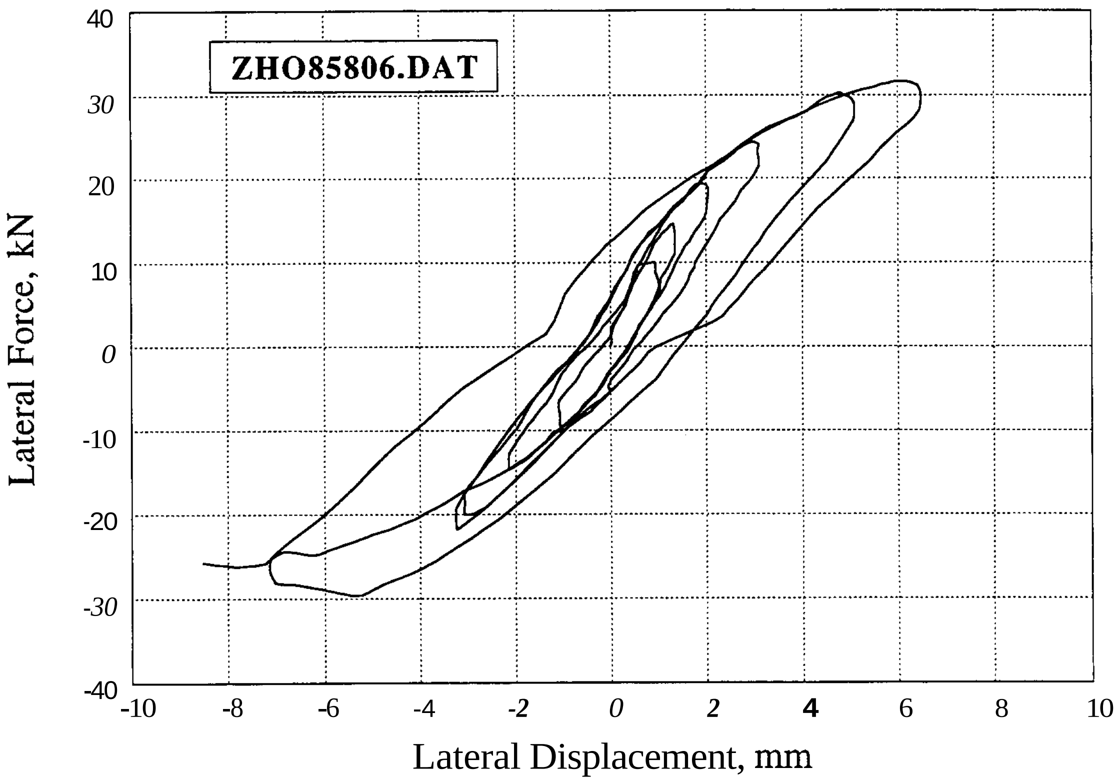


Figure 35. Specimen AZ8-06 of Zhou et al. 1985

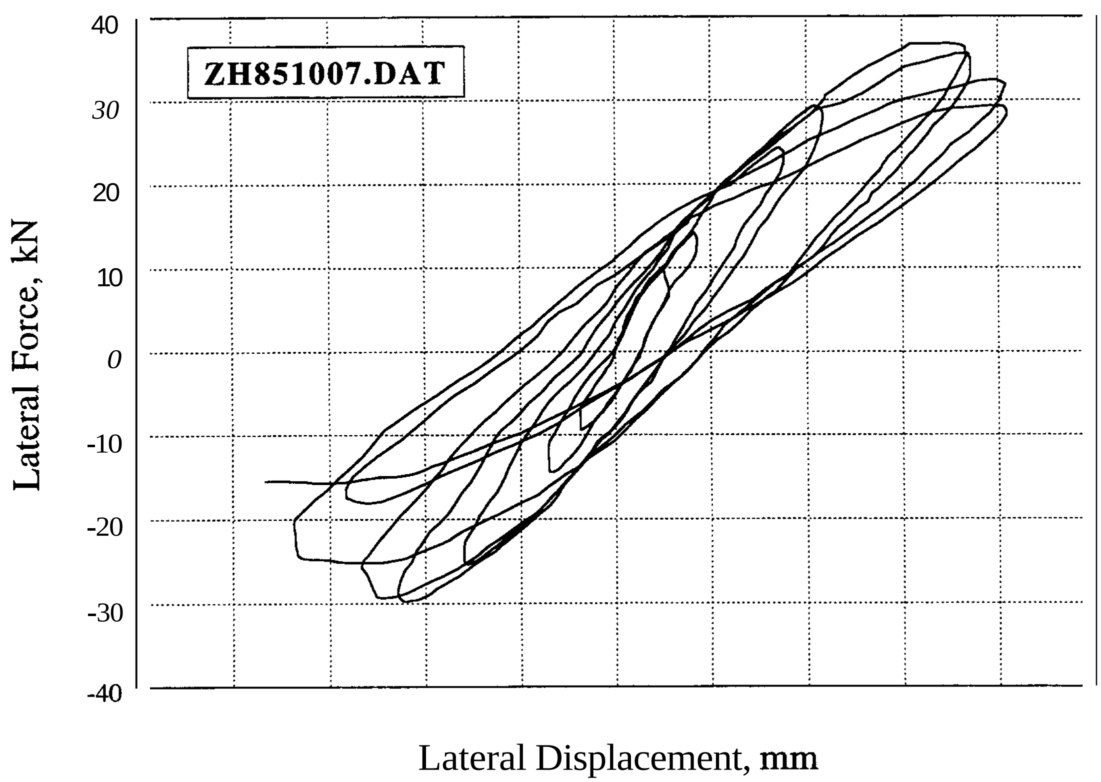


Figure 36. Specimen AZ10-07 of Zhou et al. 1985

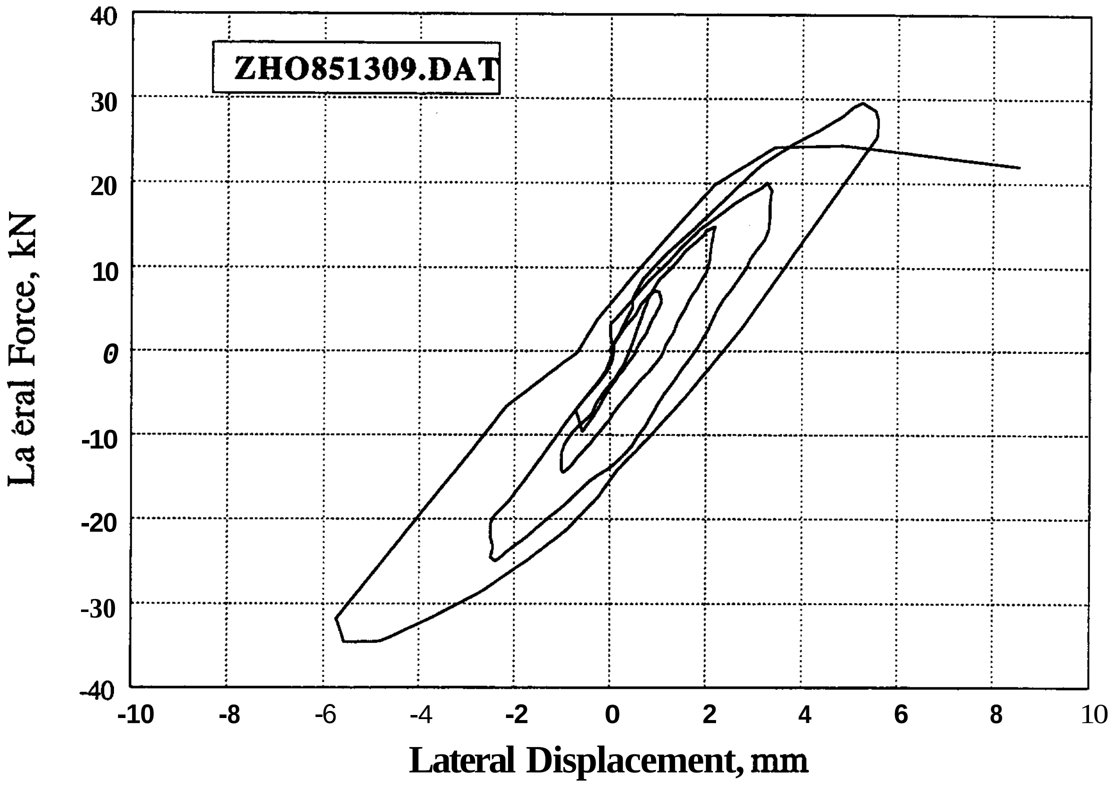


Figure 37. Specimen AZ13-09 of Zhou et al. 1985

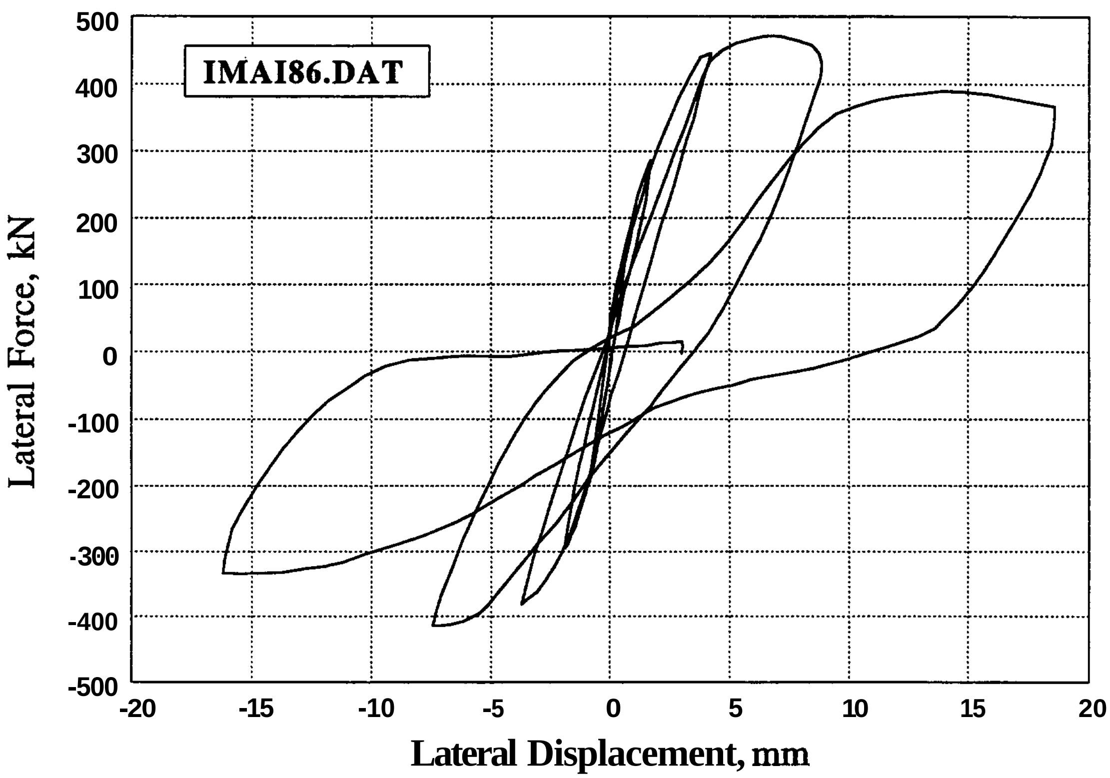


Figure 38. Specimen 1 of Imai and Yamamoto 1986

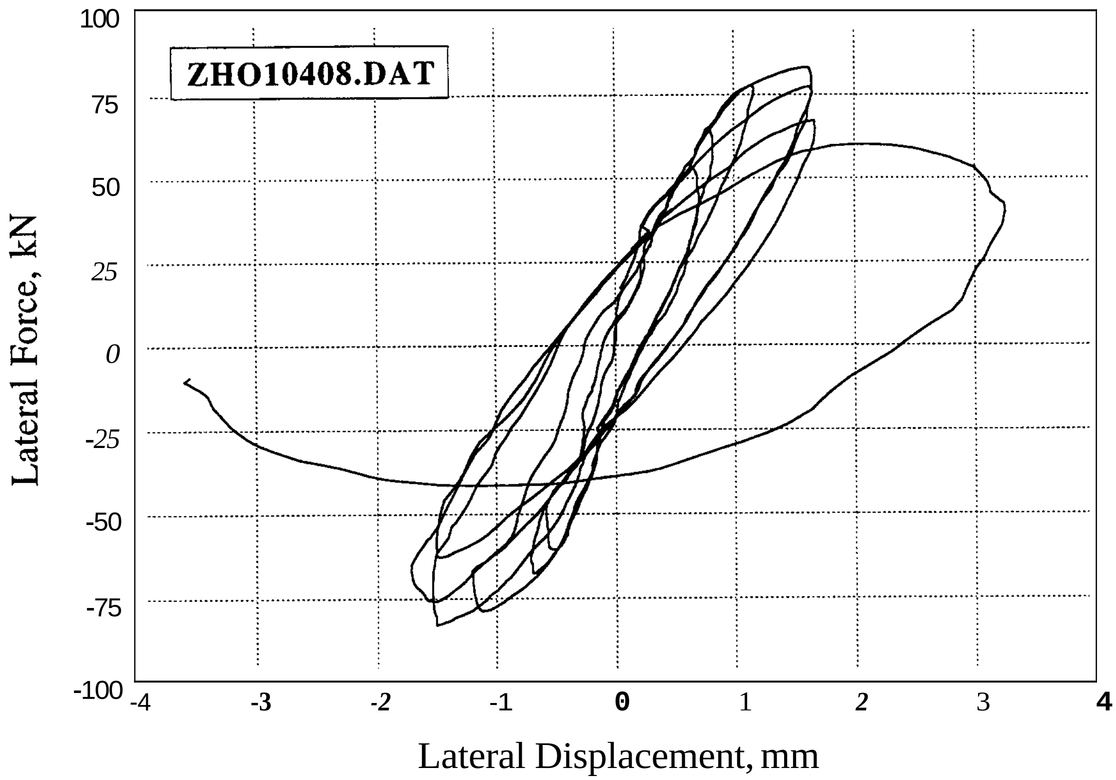


Figure 39. Specimen 104-08 of Zhou et al. 1987

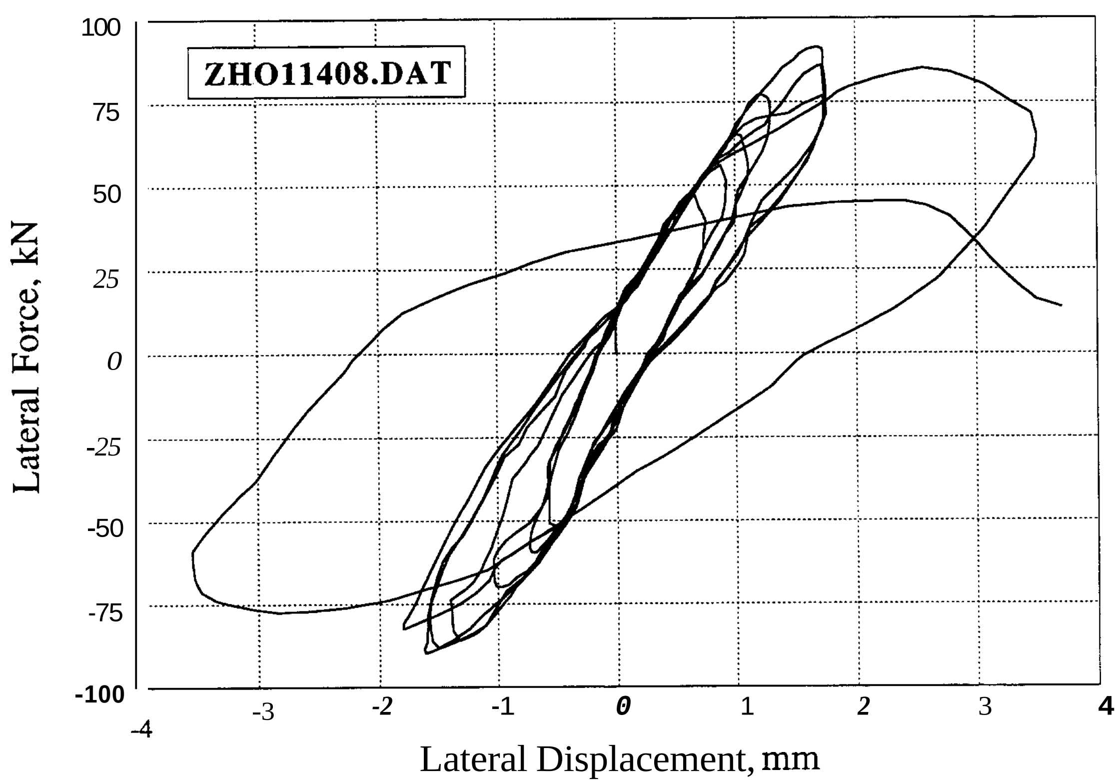


Figure **40.** Specimen 114-08 of Zhou et al. 1987

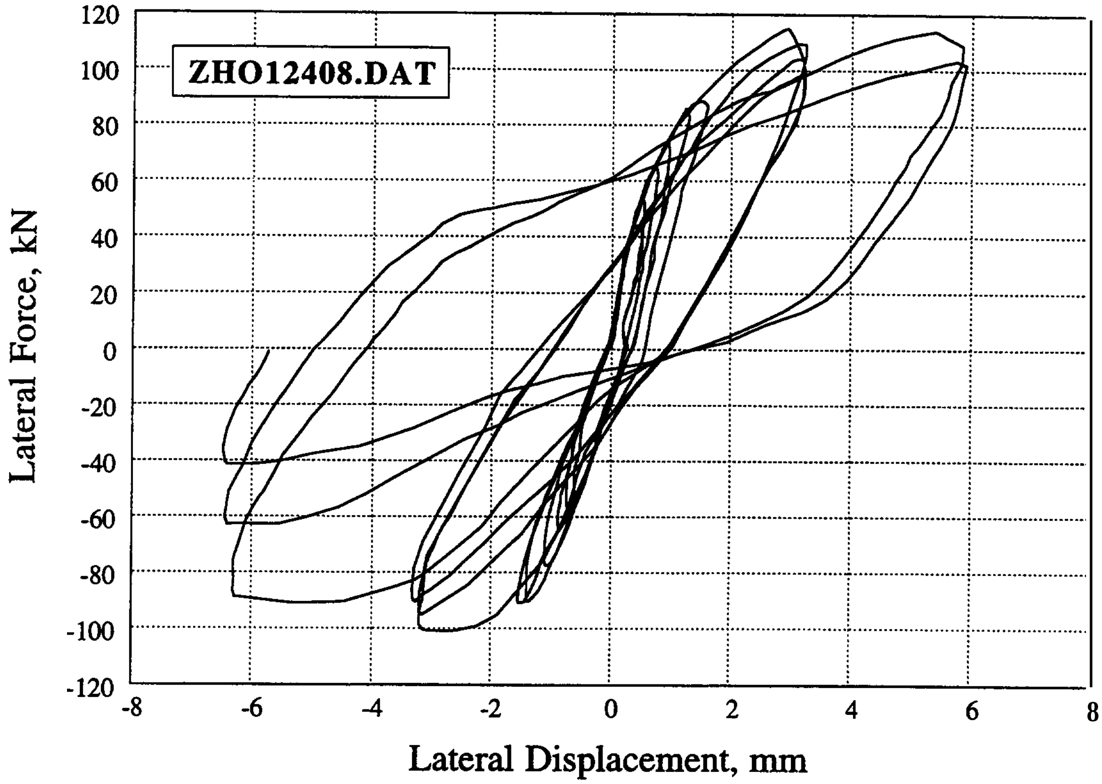


Figure 41. Specimen 124-08 of Zhou et al. 1987

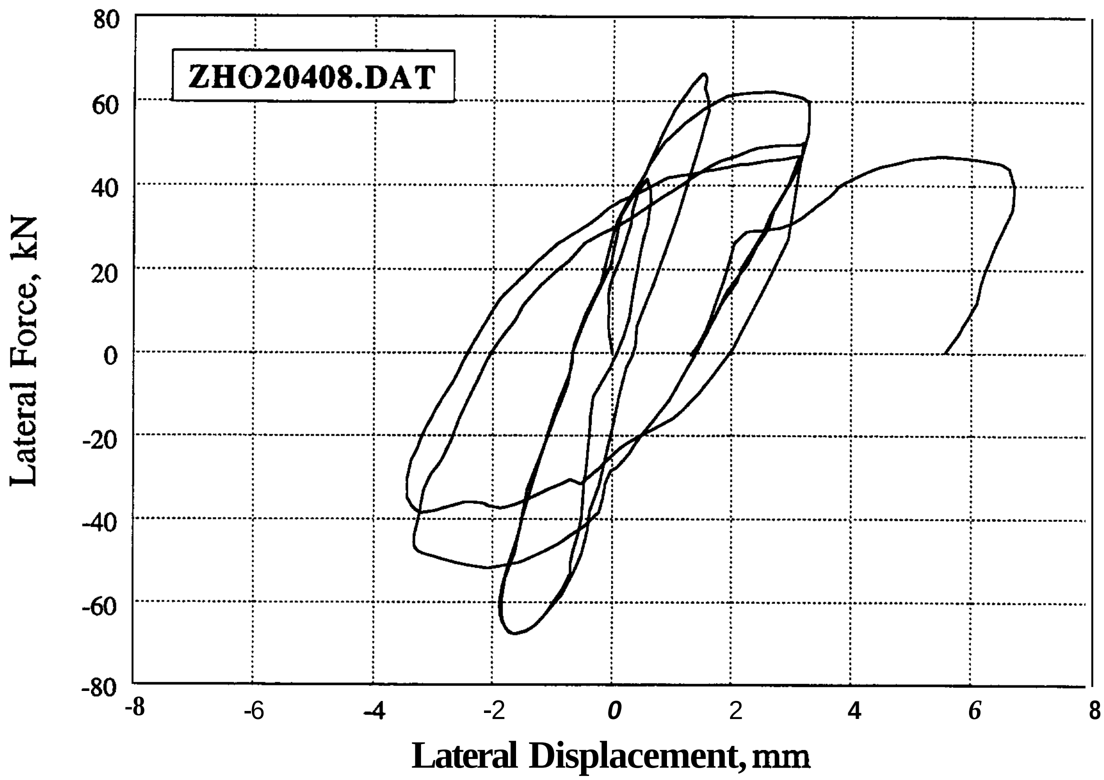


Figure 42. Specimen 204-08 of Zhou et al. 1987

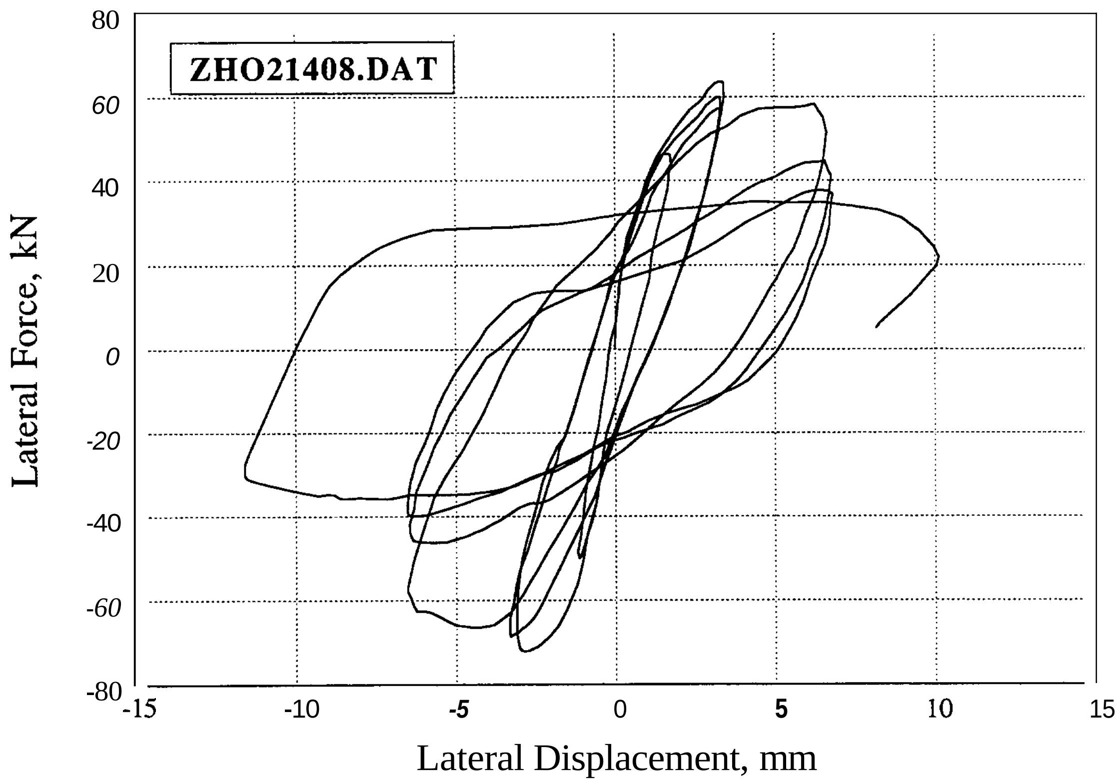


Figure 43. Specimen 214-08 of Zhou et al. 1987

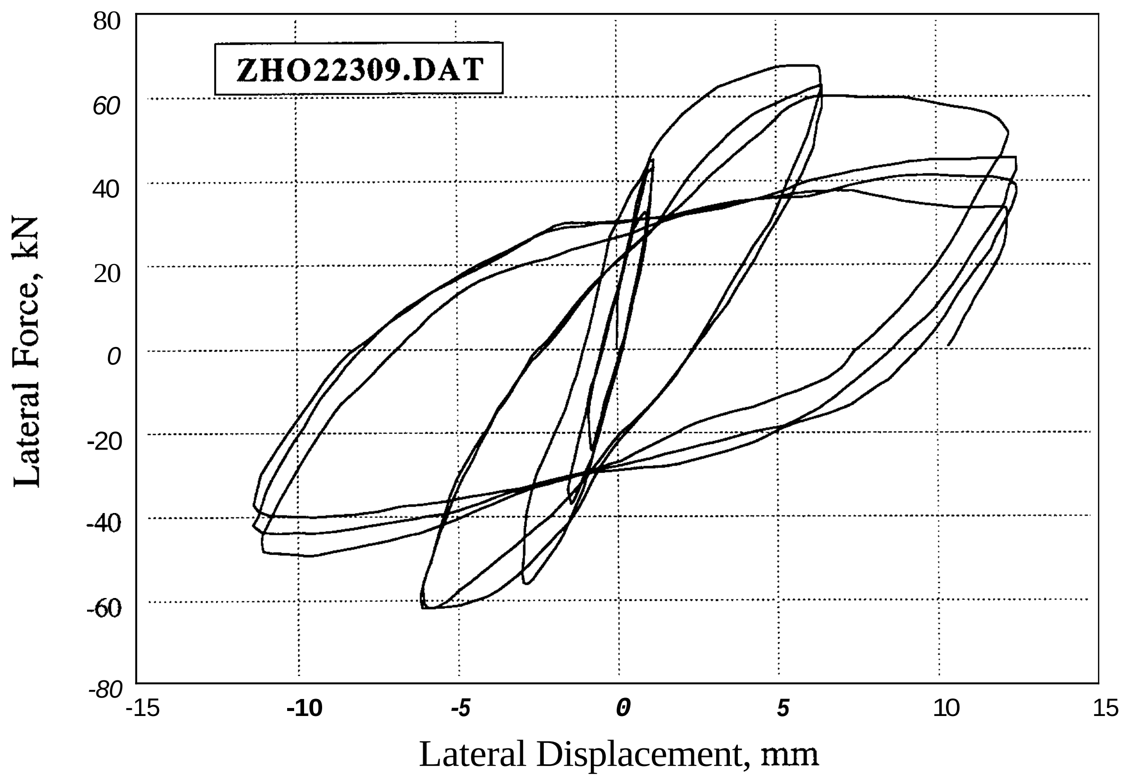


Figure 44. Specimen 223-09 of Zhou et al. 1987

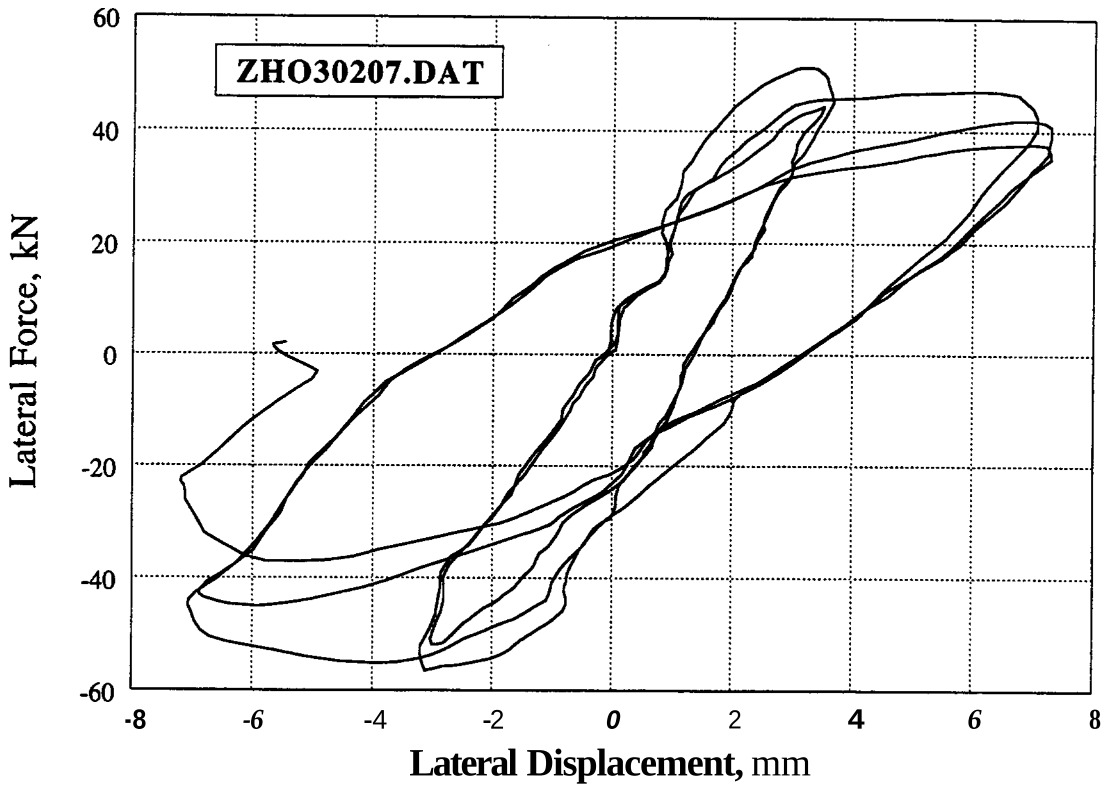


Figure 45. Specimen 302-07 of Zhou et al. 1987

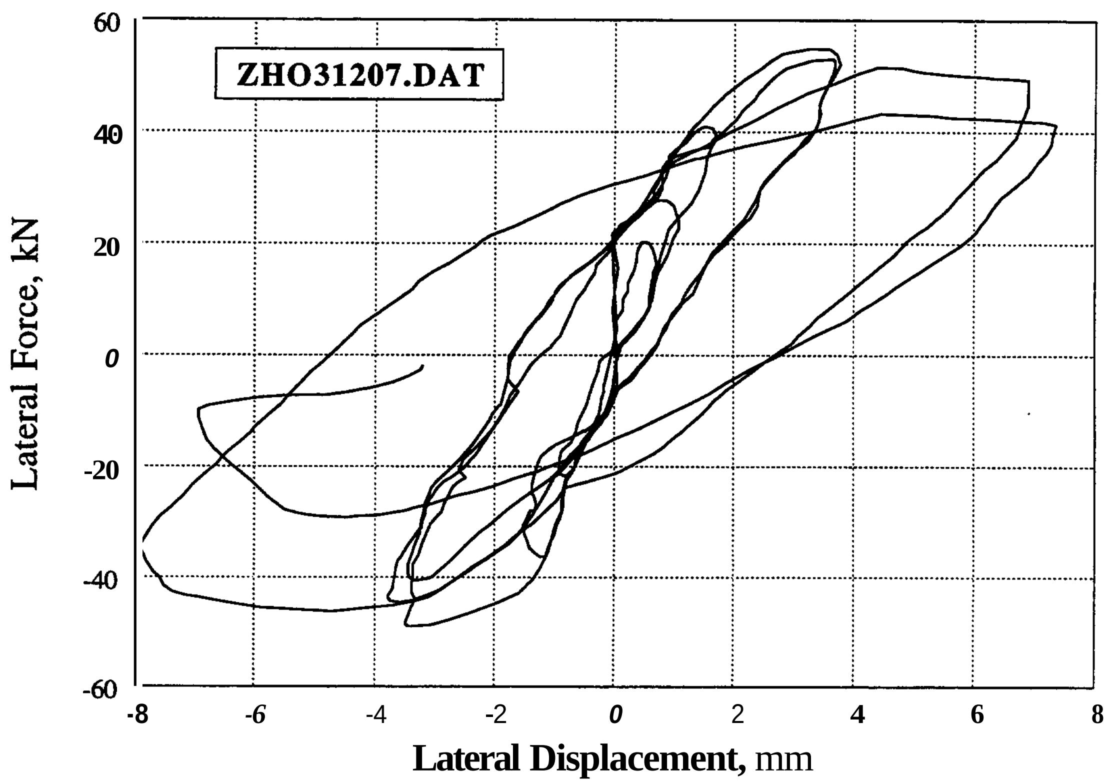


Figure 46. Specimen 312-07 of Zhou et al. 1987

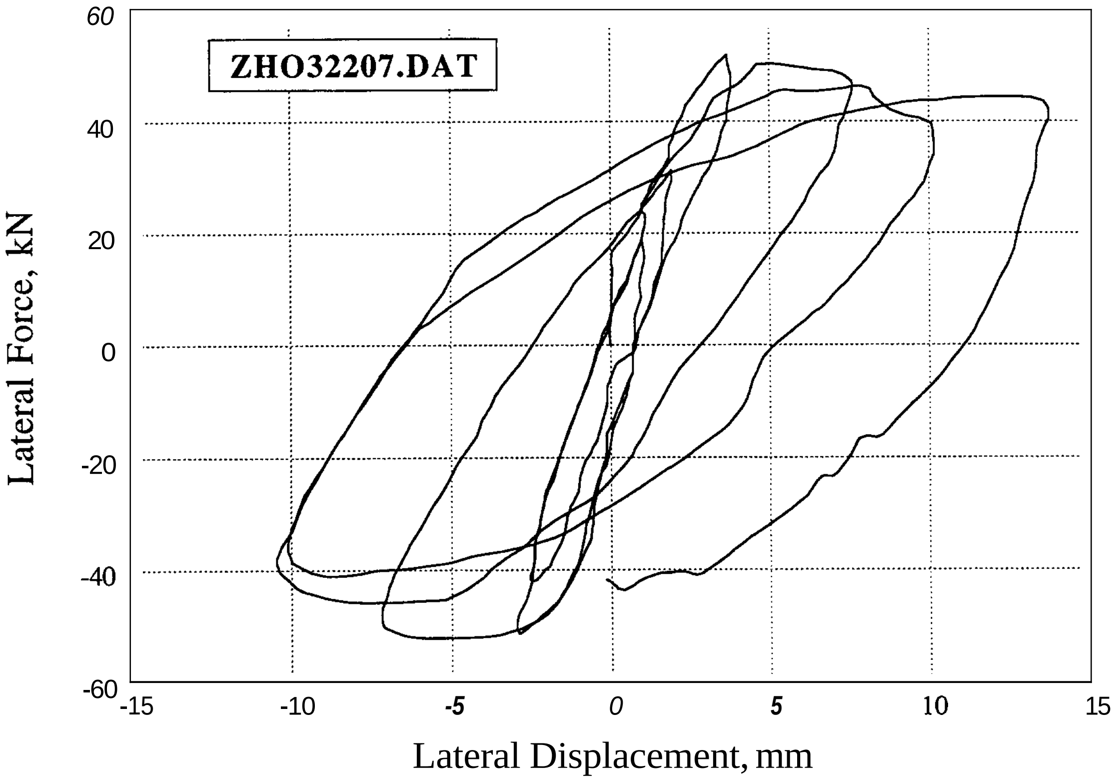


Figure 47. Specimen 322-07 of **Zhou** et al. 1987

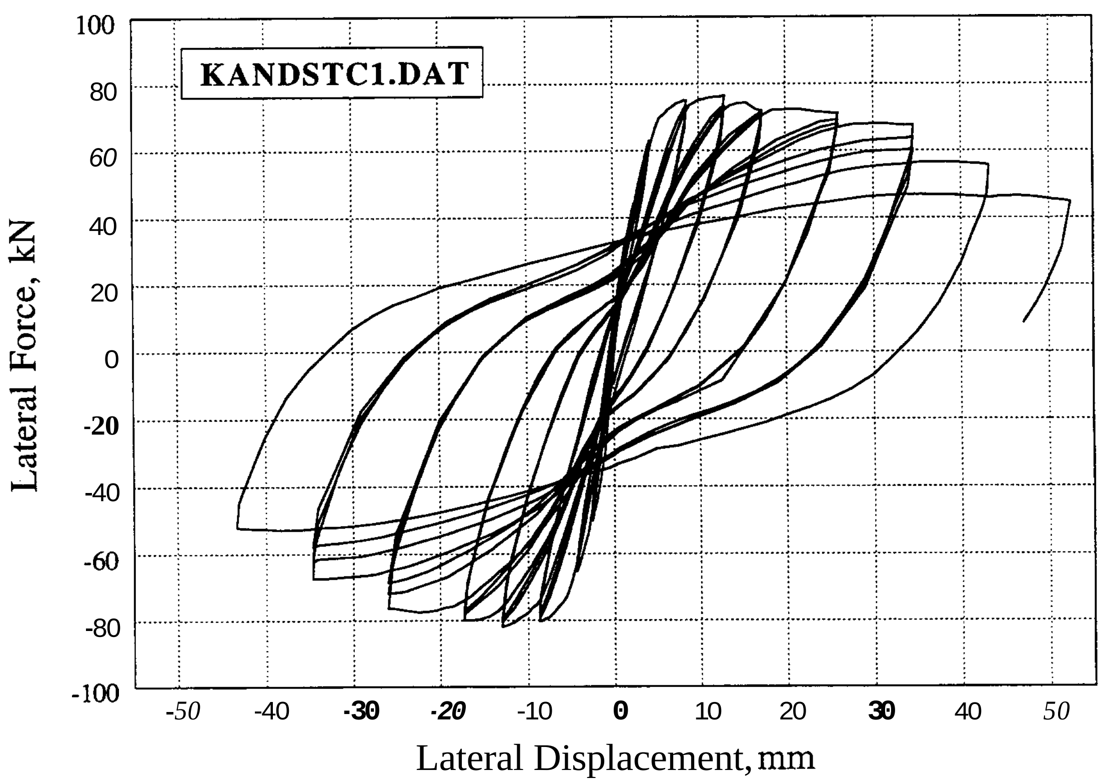


Figure 48. Specimen STC1 of Kanda et al. 1988

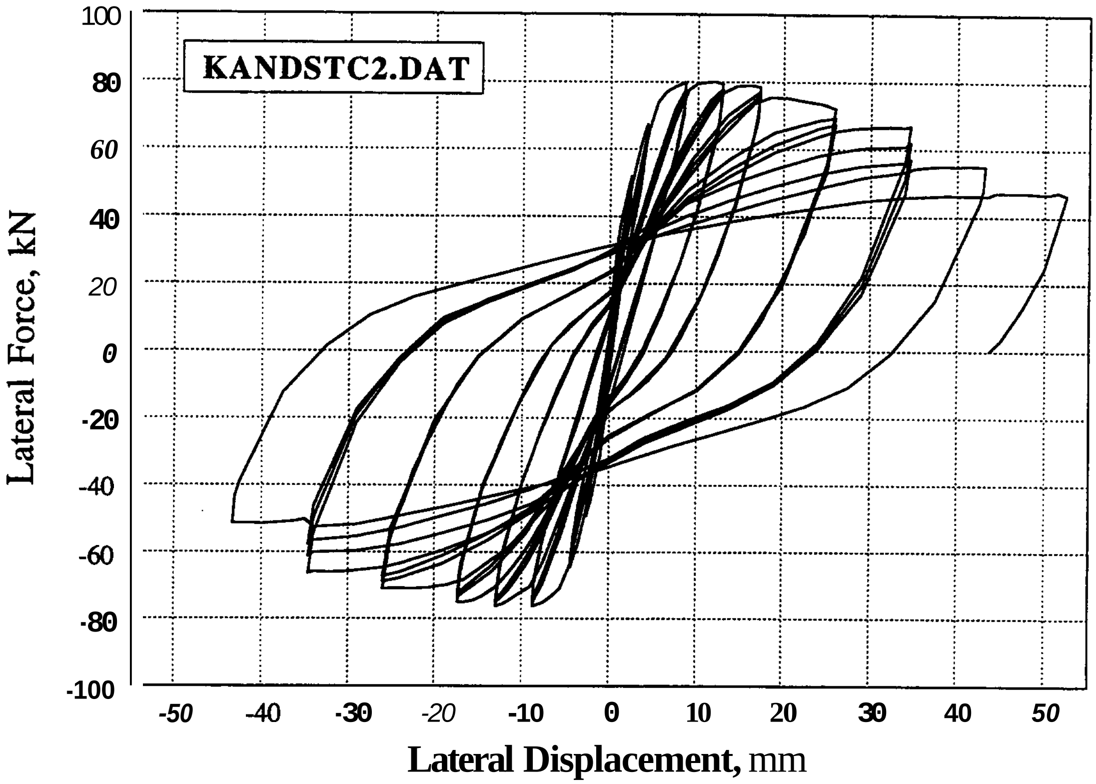


Figure 49. Specimen STC2 of Kanda et al. 1988

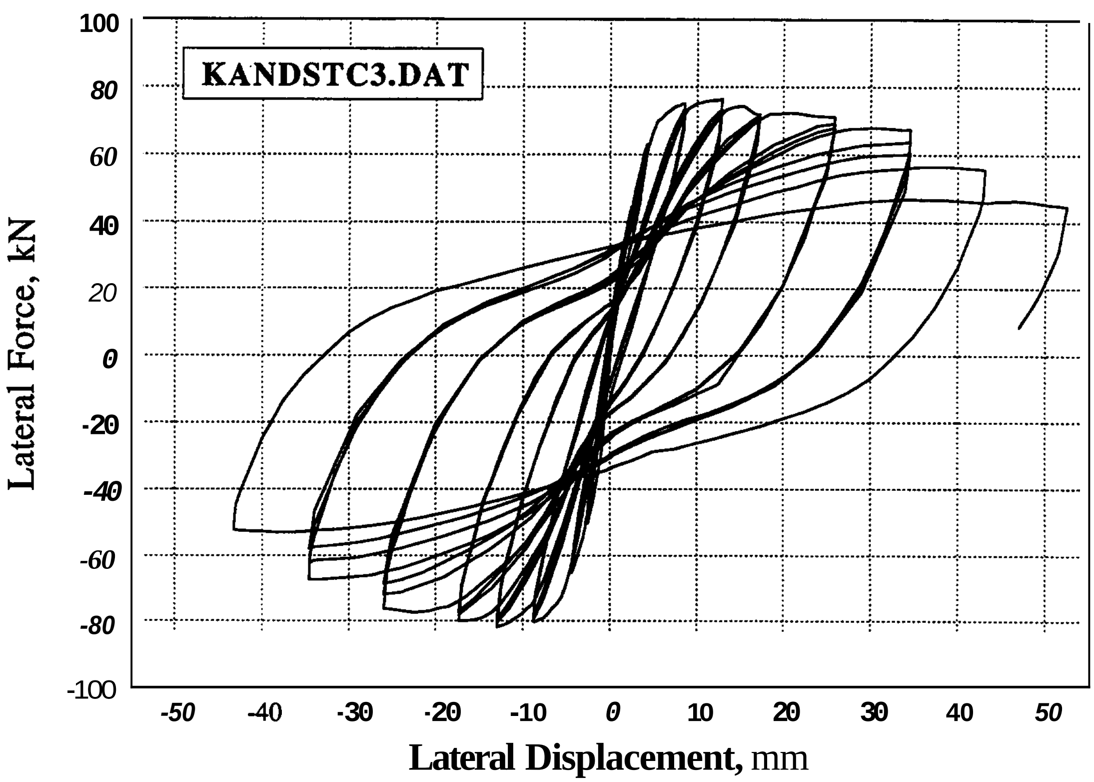


Figure 50. Specimen STC3 of Kanda et al. 1988

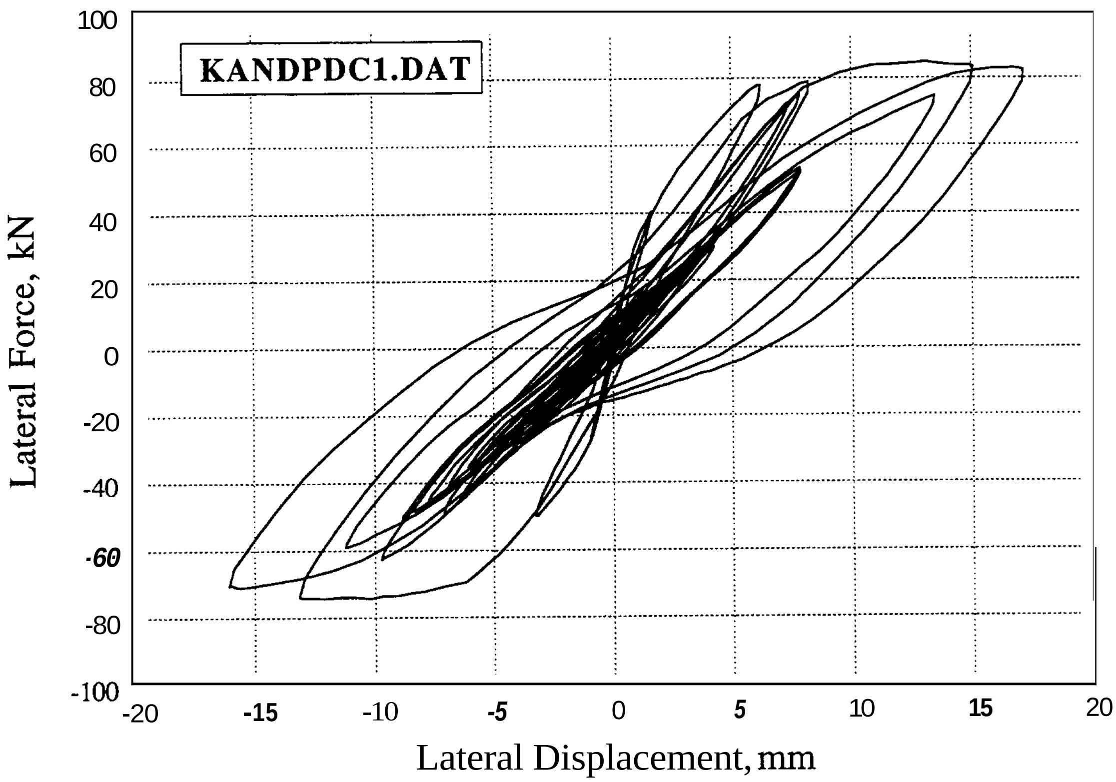


Figure 51. Specimen PDC1 of Kanda et al. 1988

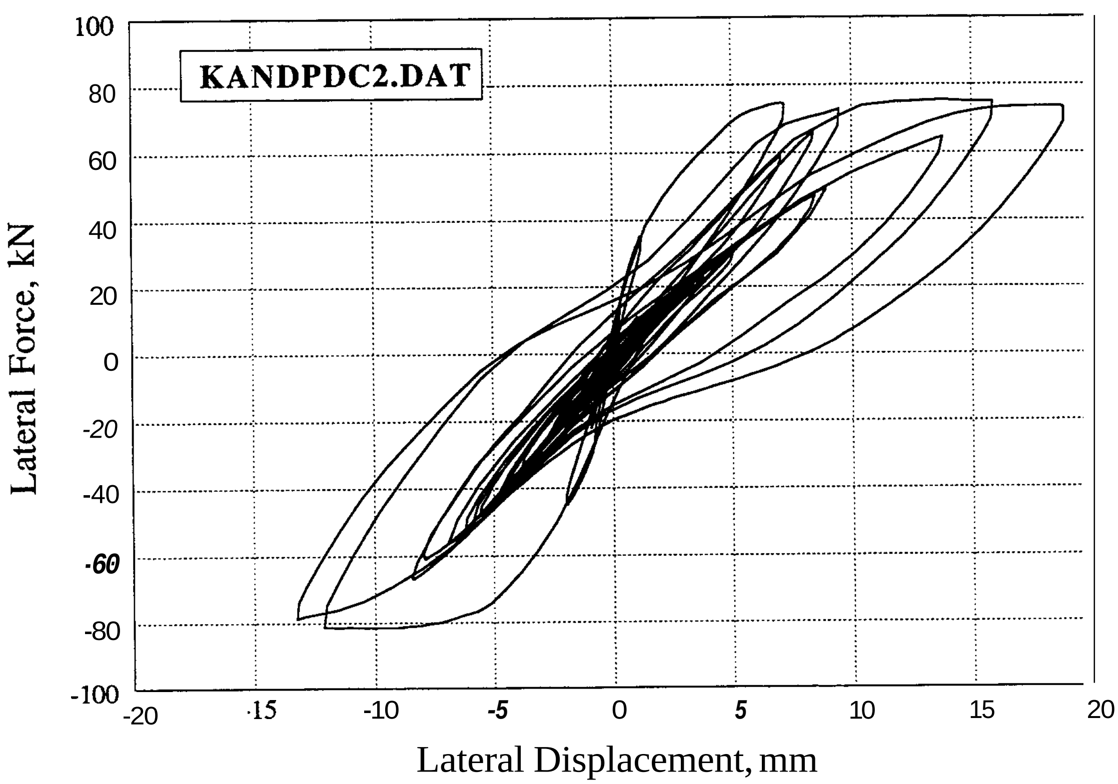


Figure 52. Specimen PDC2 of Kanda et al. 1988

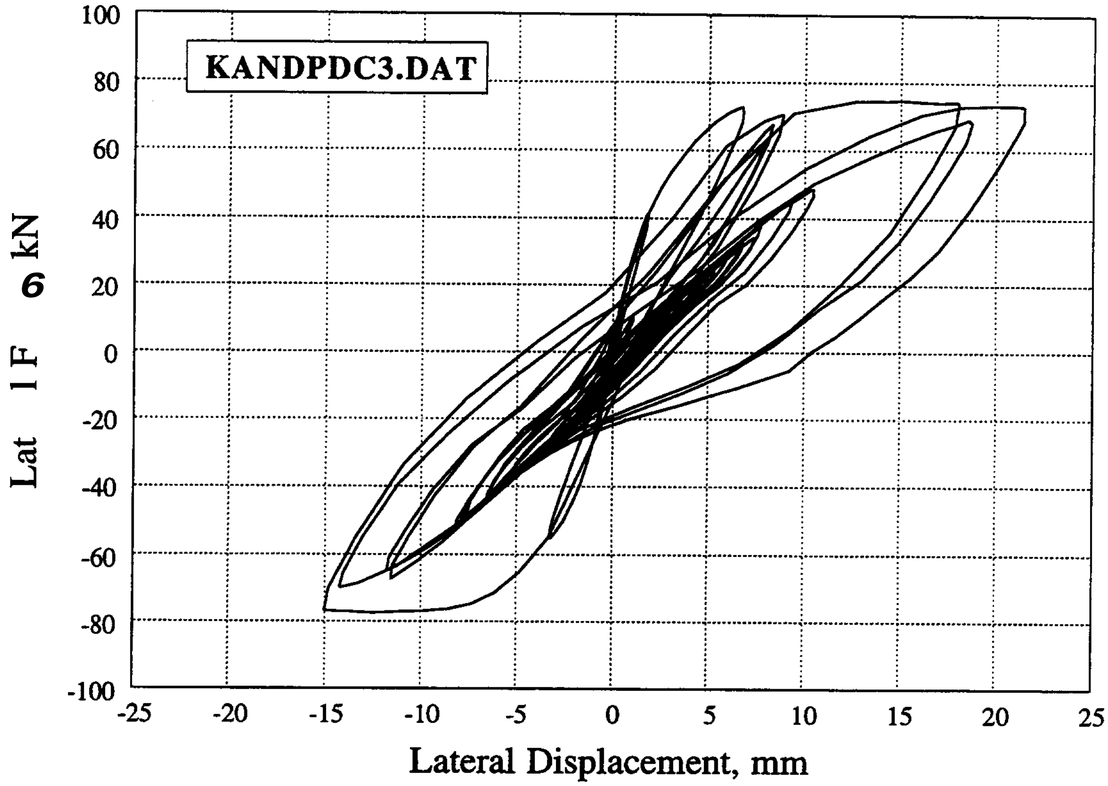


Figure 53. Specimen PDC3 of Kanda et al. 1988

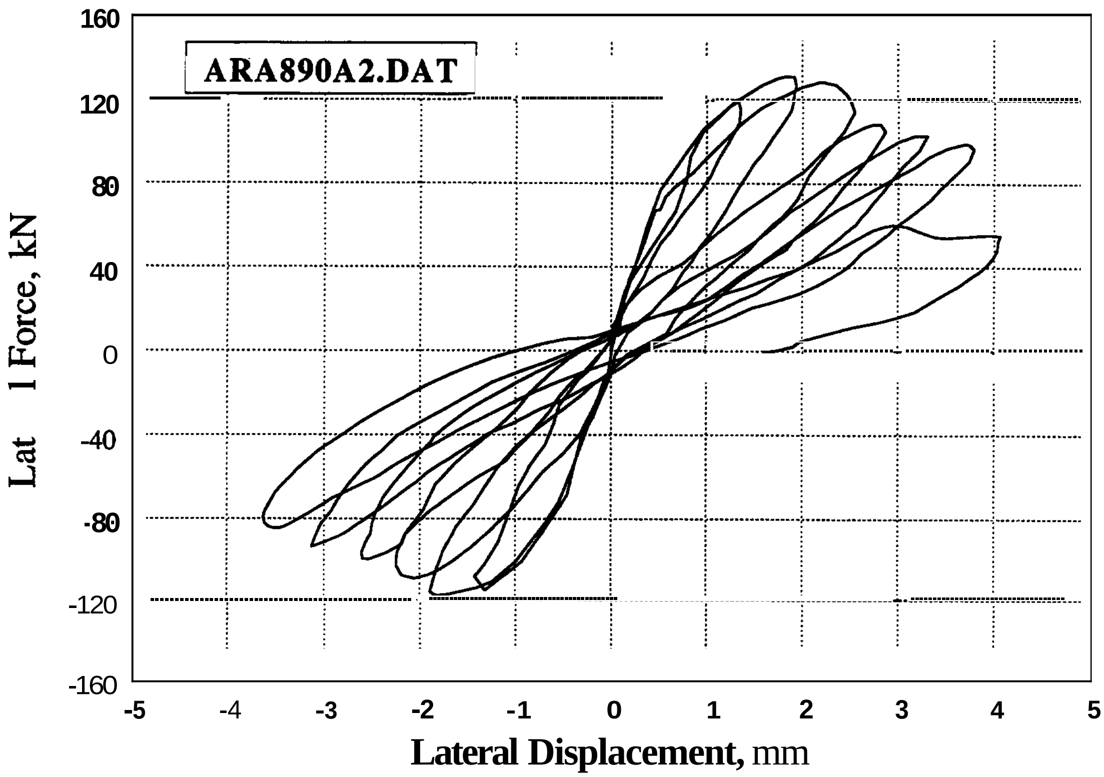


Figure 54. Specimen OA2 of Arakawa 1989

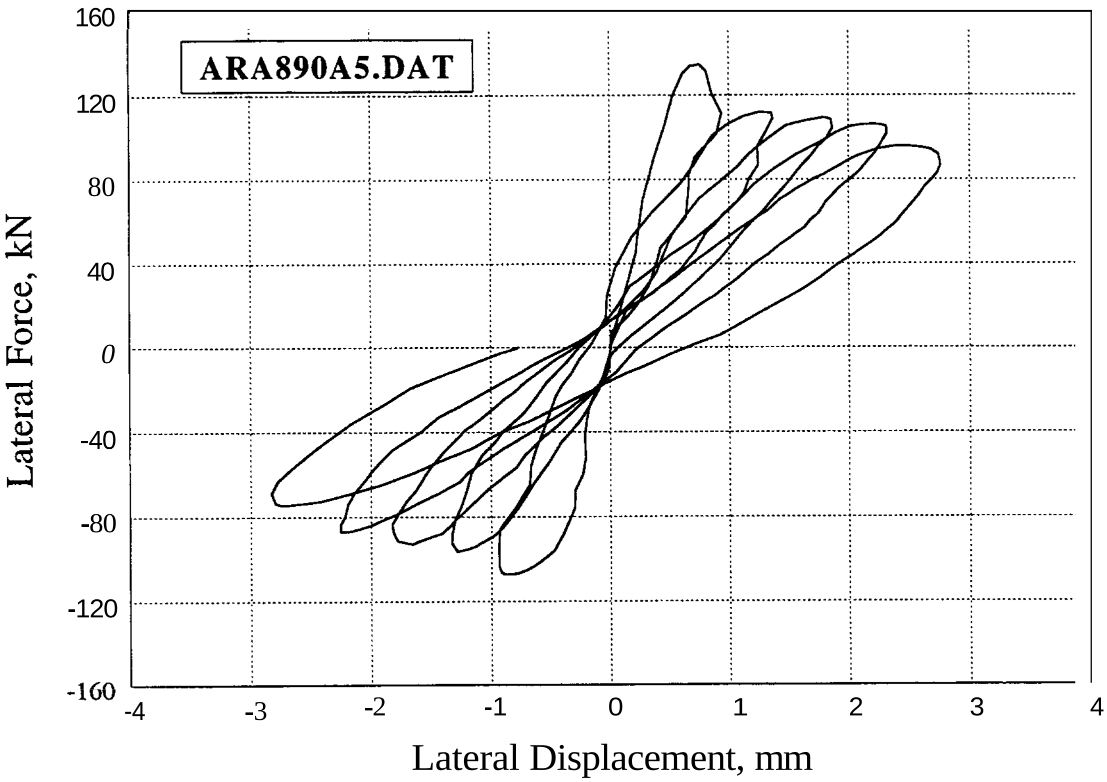


Figure 55. Specimen **OA5** of Arakawa 1989

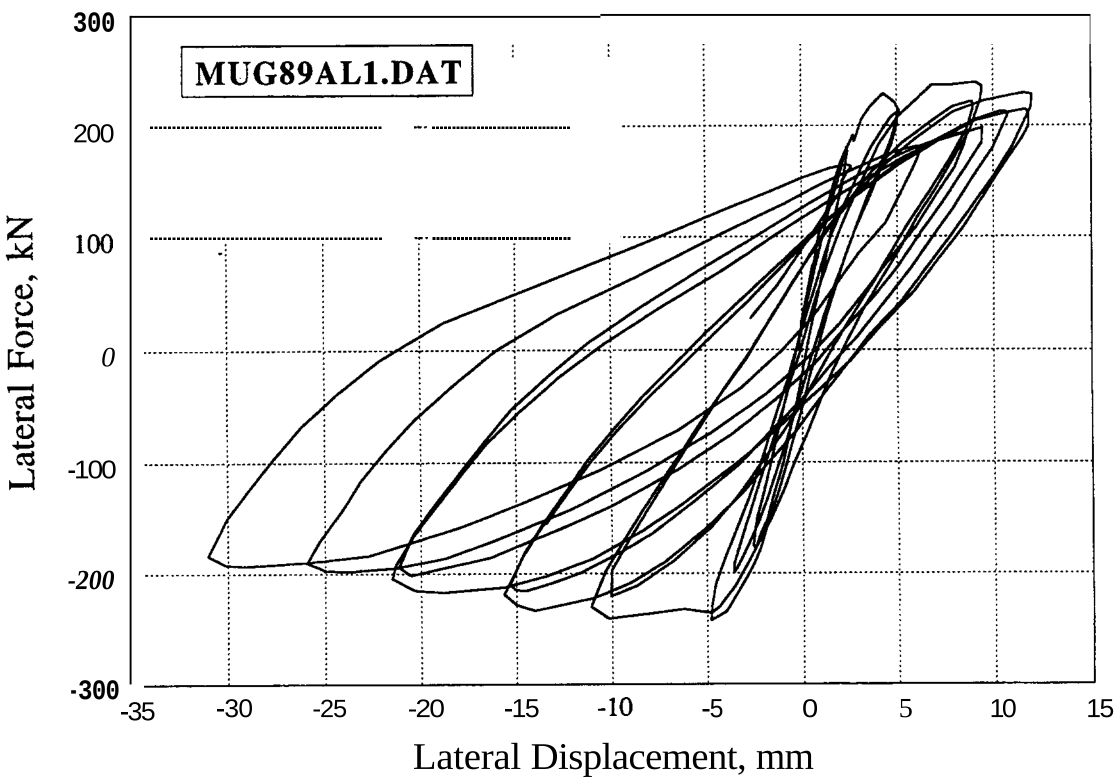


Figure 56. Specimen AL-1 of Muguruma 1989

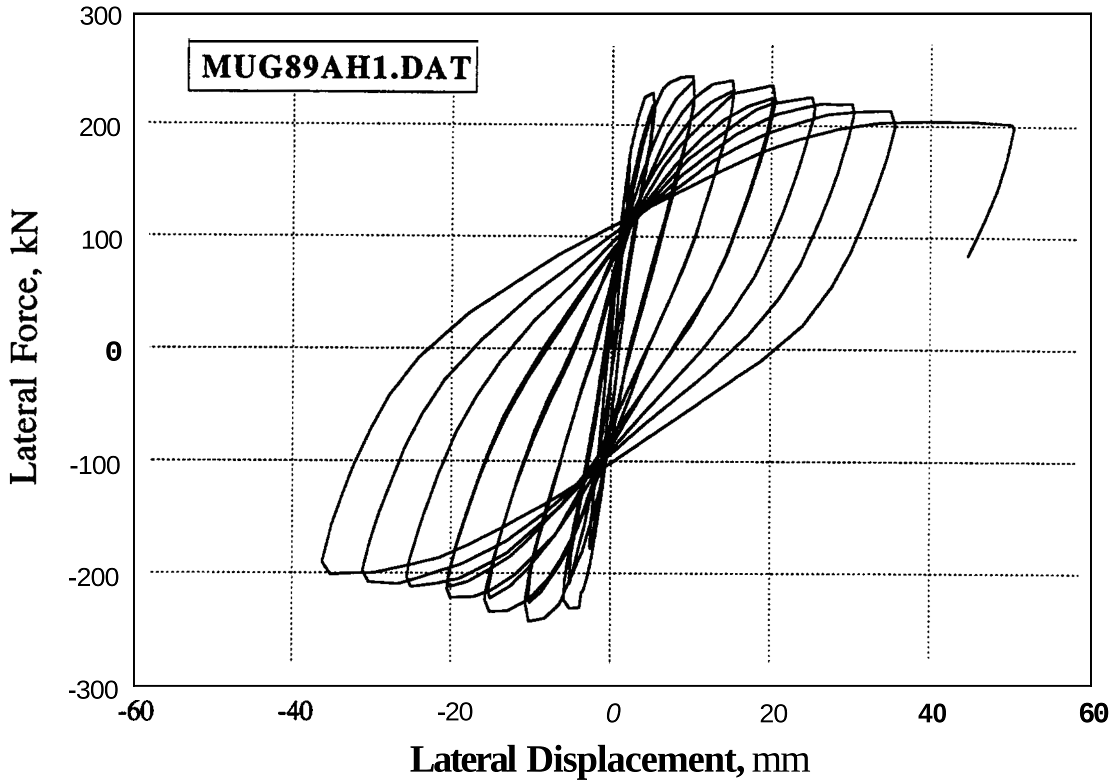


Figure 57. Specimen AH-1 of Muguruma 1989

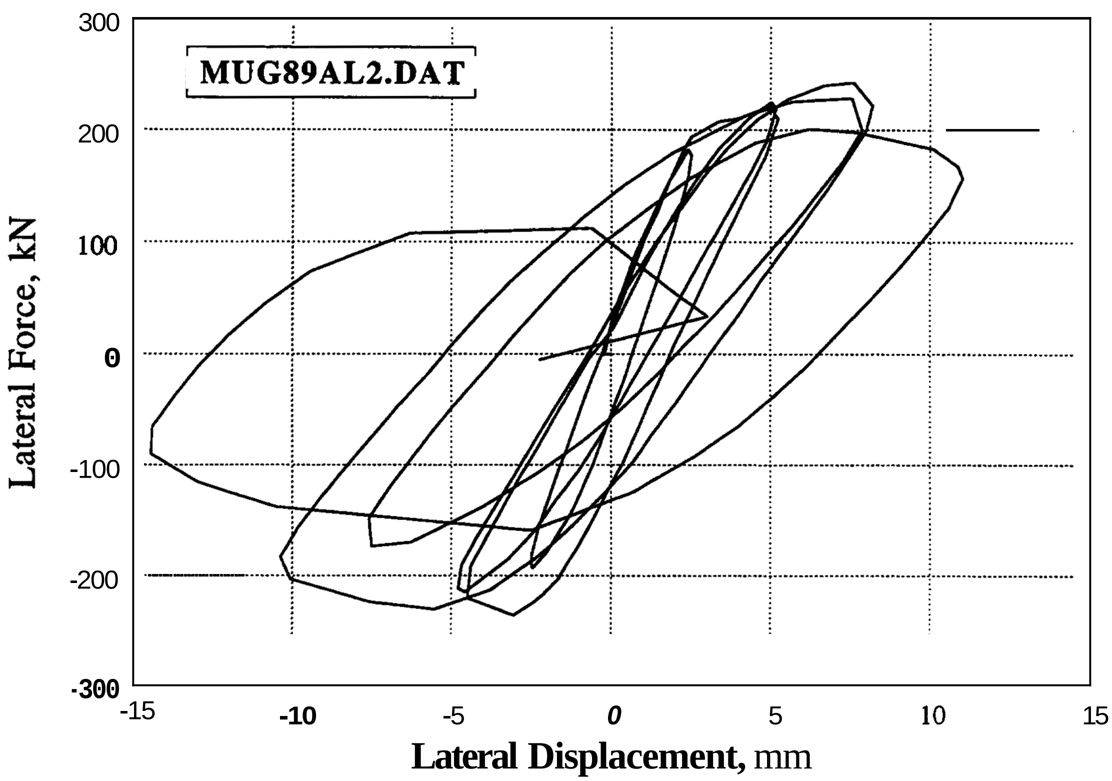


Figure 58. Specimen AL-2 of Muguruma 1989

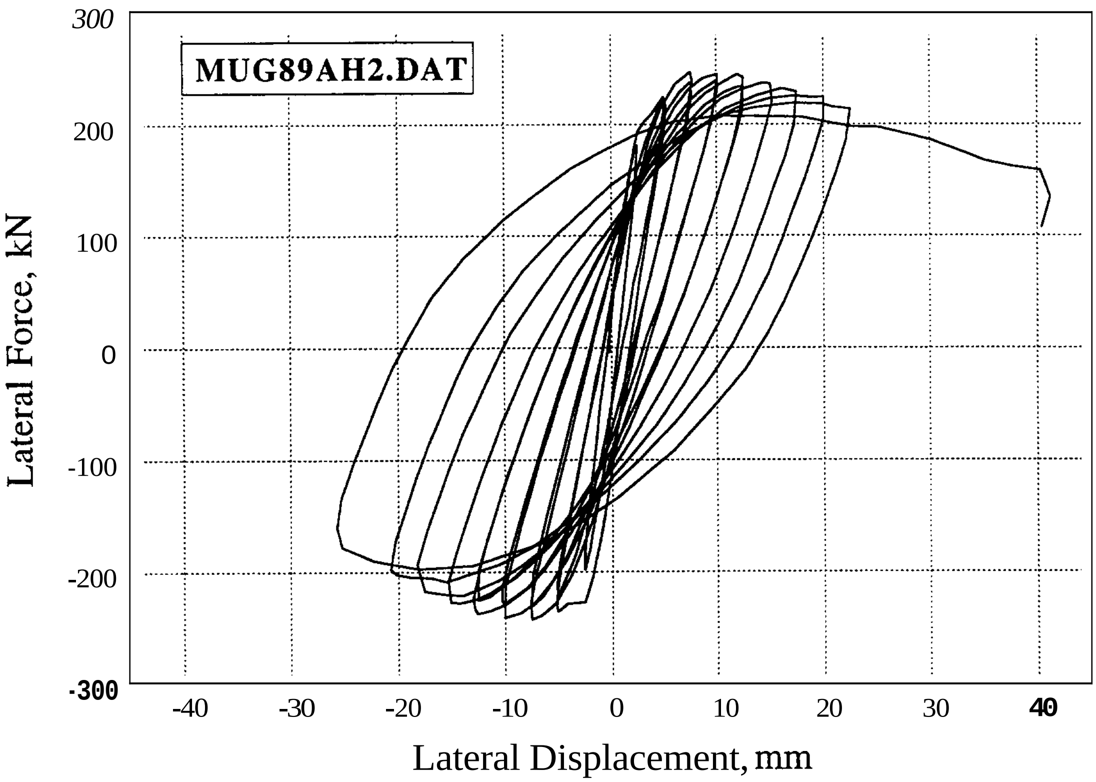


Figure 59. Specimen ***AH-2*** **of** Muguruma 1989

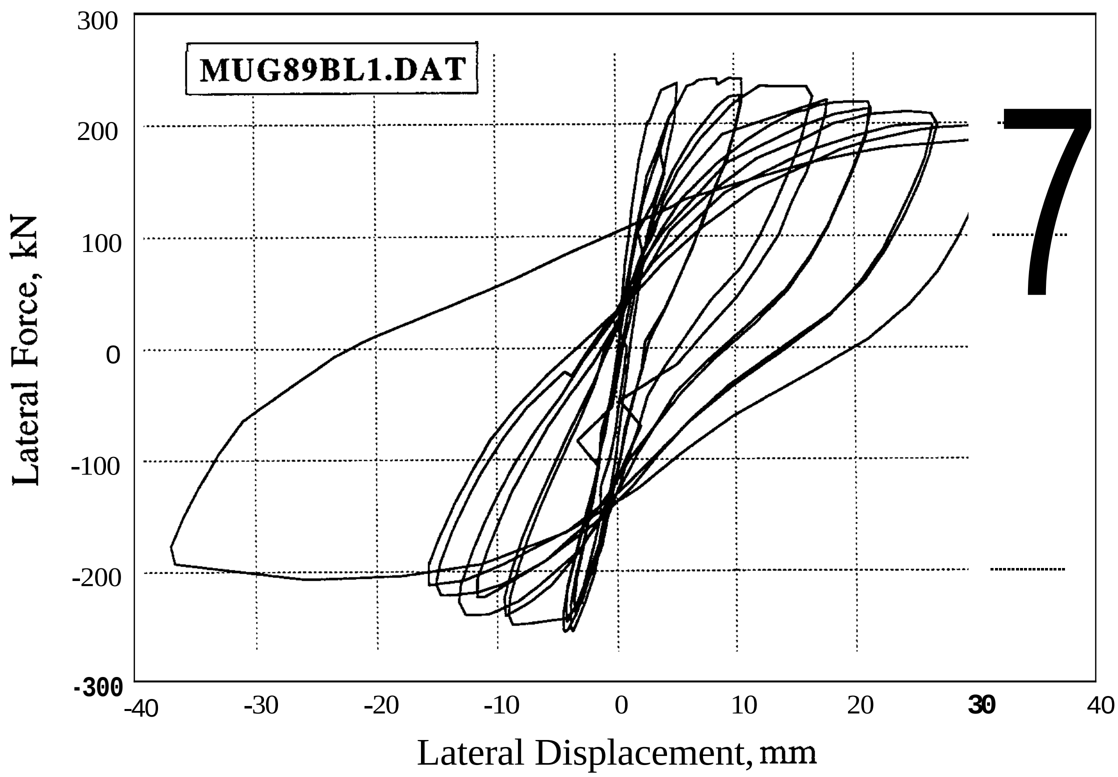


Figure **60.** Specimen BL-1 **of** Muguruma **1989**

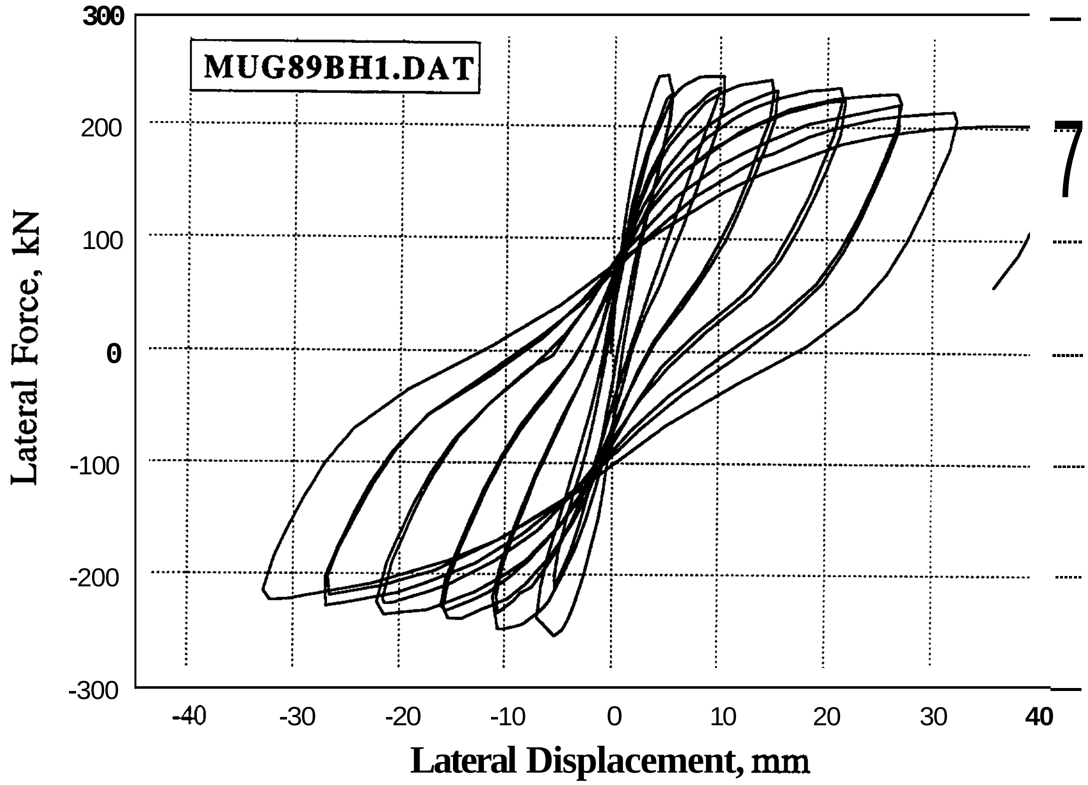


Figure 61. Specimen BH-1 of Muguruma 1989

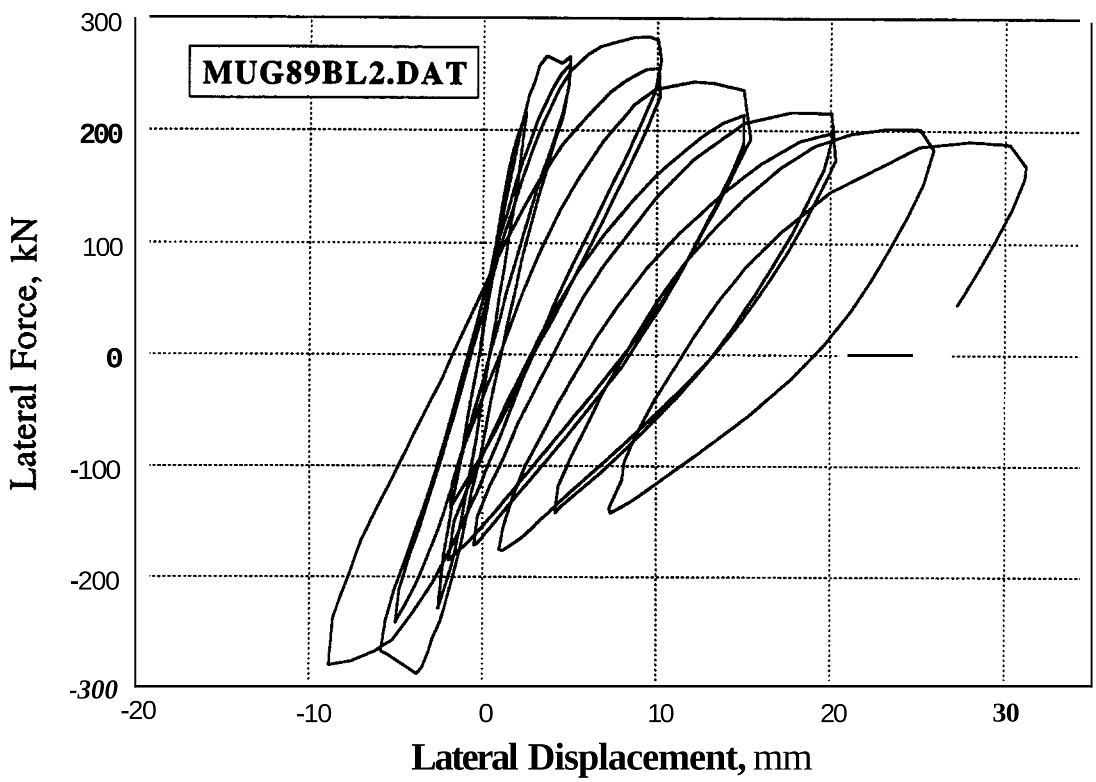


Figure 62. Specimen BL-2 of Muguruma 1989

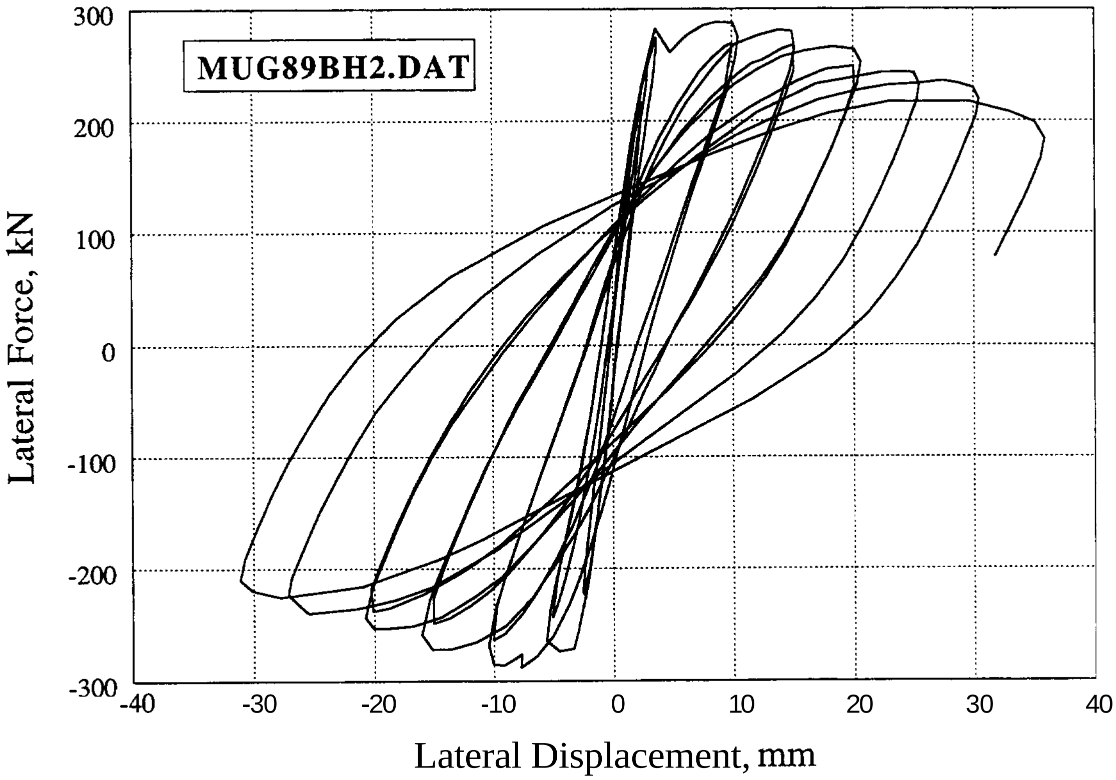


Figure 63. Specimen BH-2 of Muguruma 1989

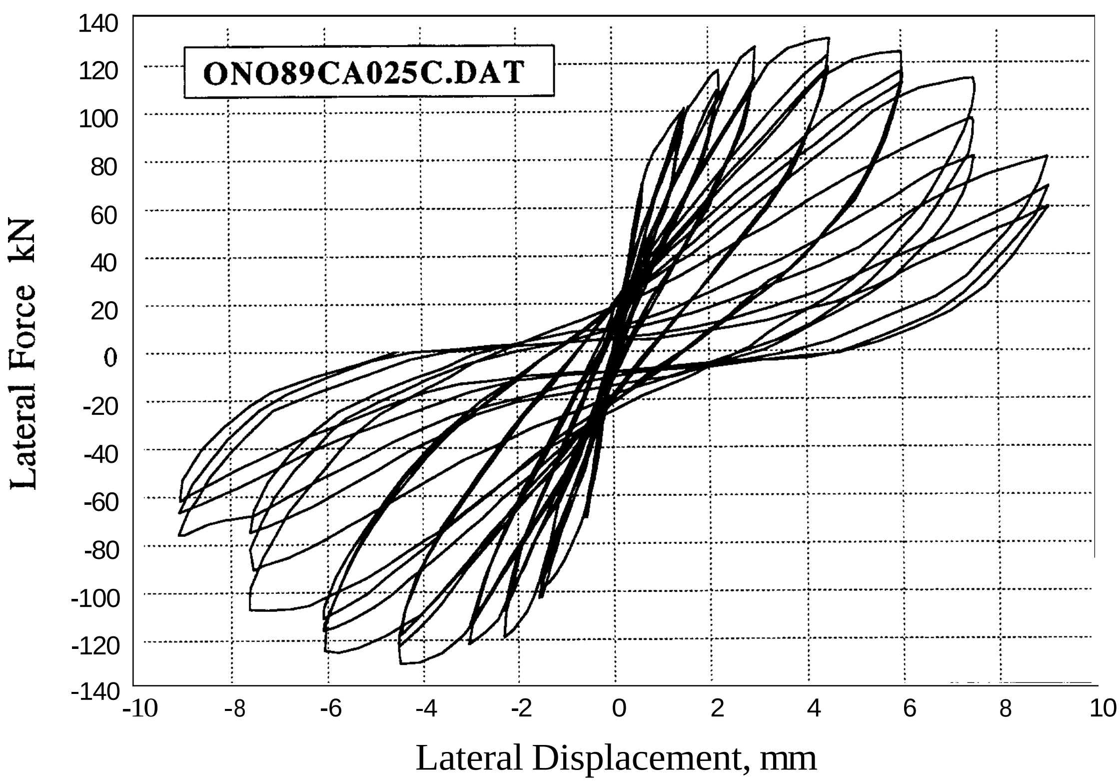


Figure ***64.*** Specimen CA025C of Ono 1989

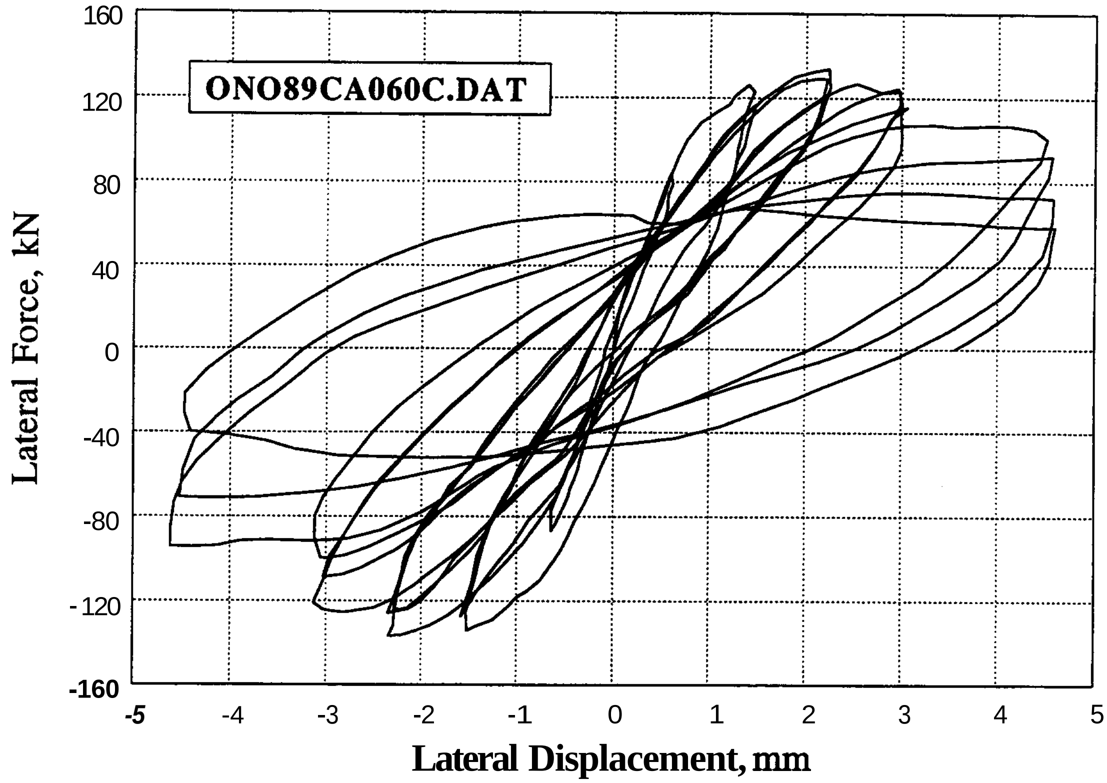


Figure 65. Specimen CA060C of Ono 1989

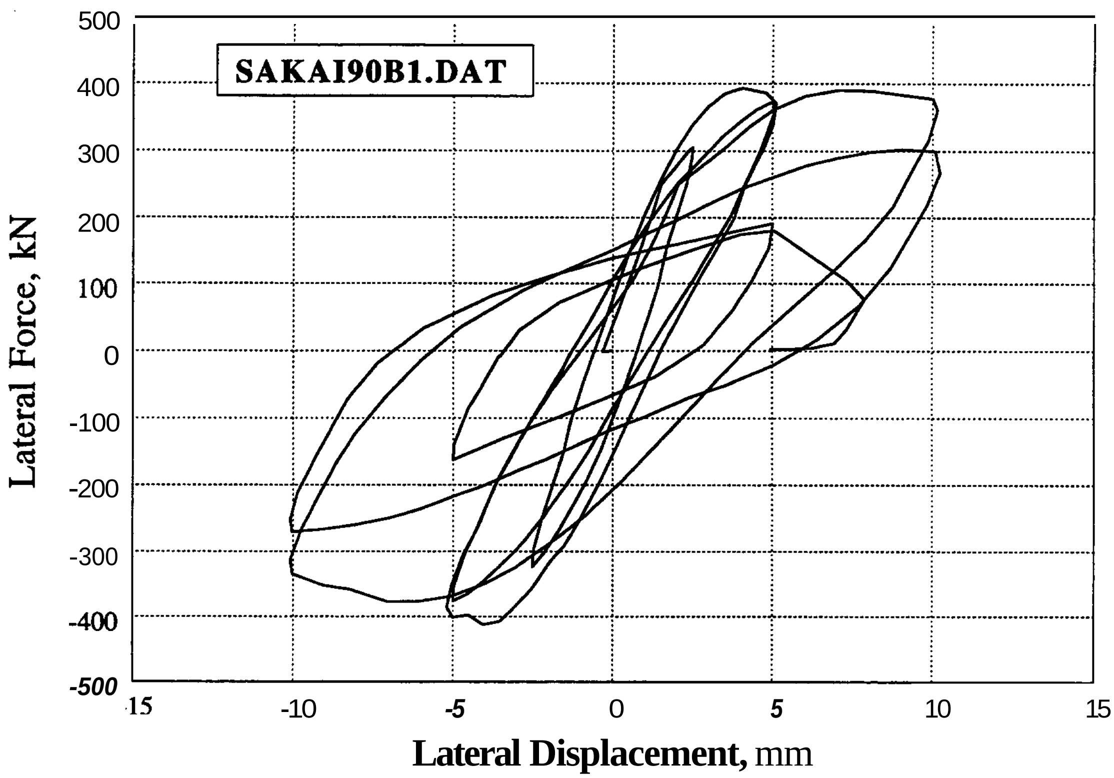


Figure 66. Specimen B1 of Sakai 1990

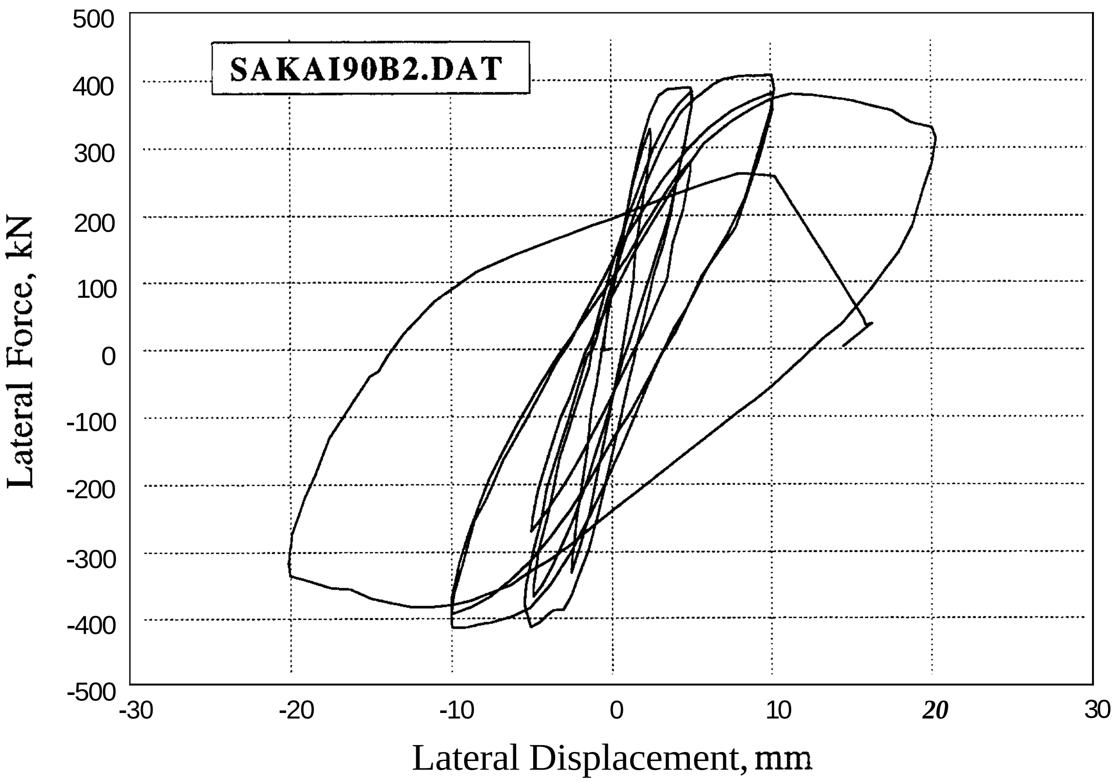


Figure 67. Specimen **B2 of** Sakai 1990

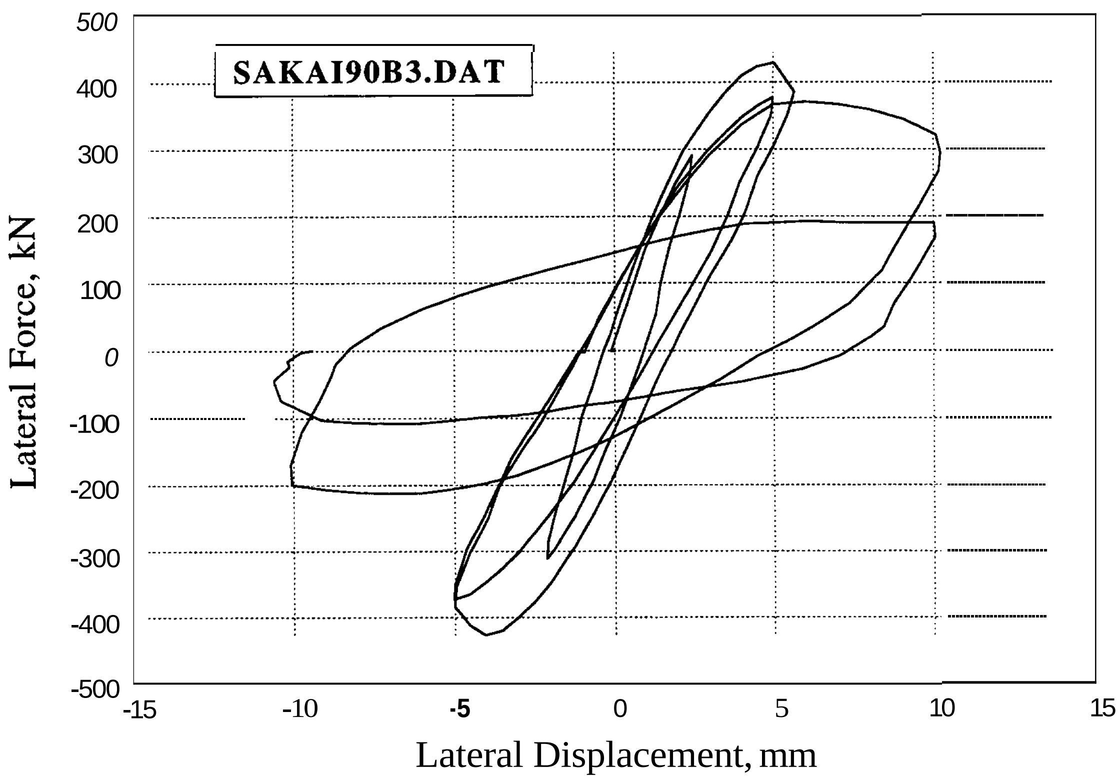


Figure 68. Specimen **B3 of Sakai** 1990

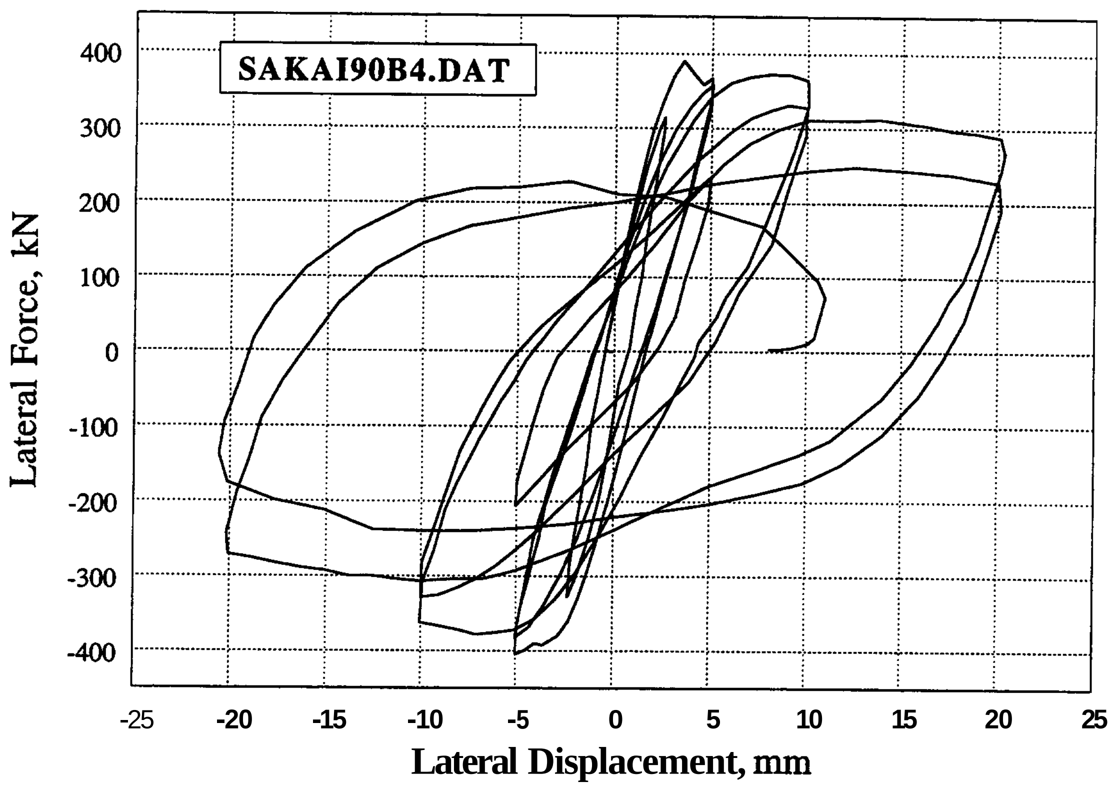


Figure 69. Specimen B4 of Sakai 1990

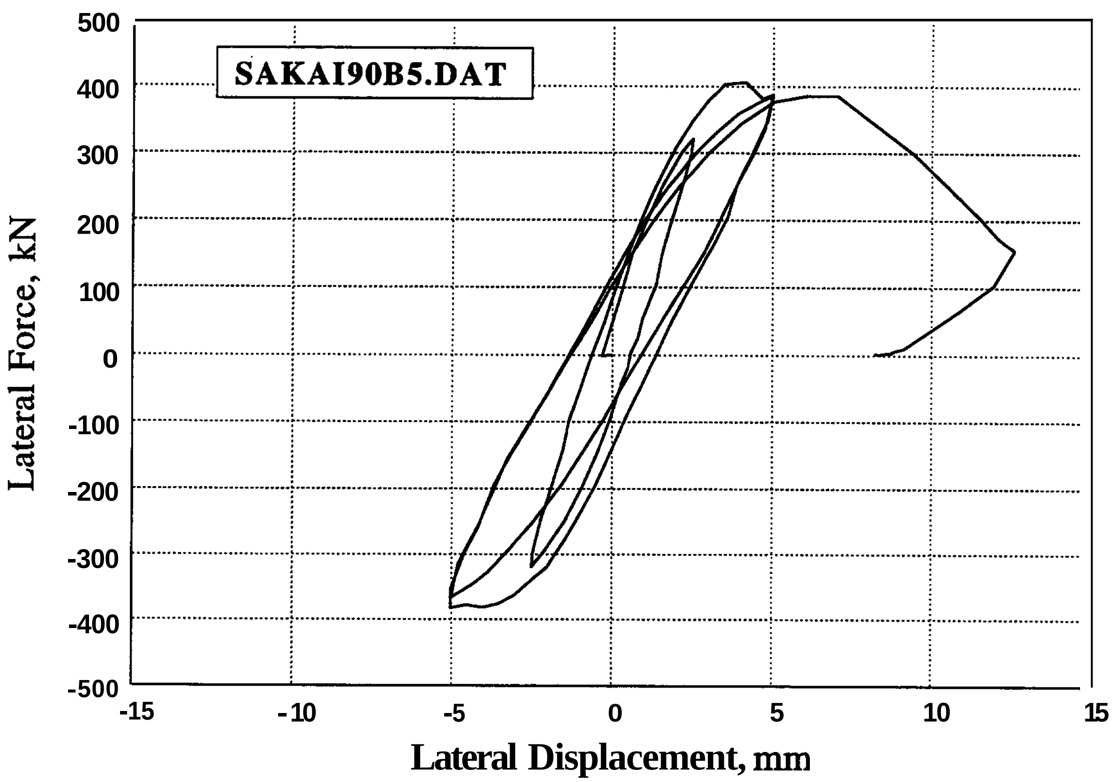


Figure 70. Specimen B5 of Sakai 1990

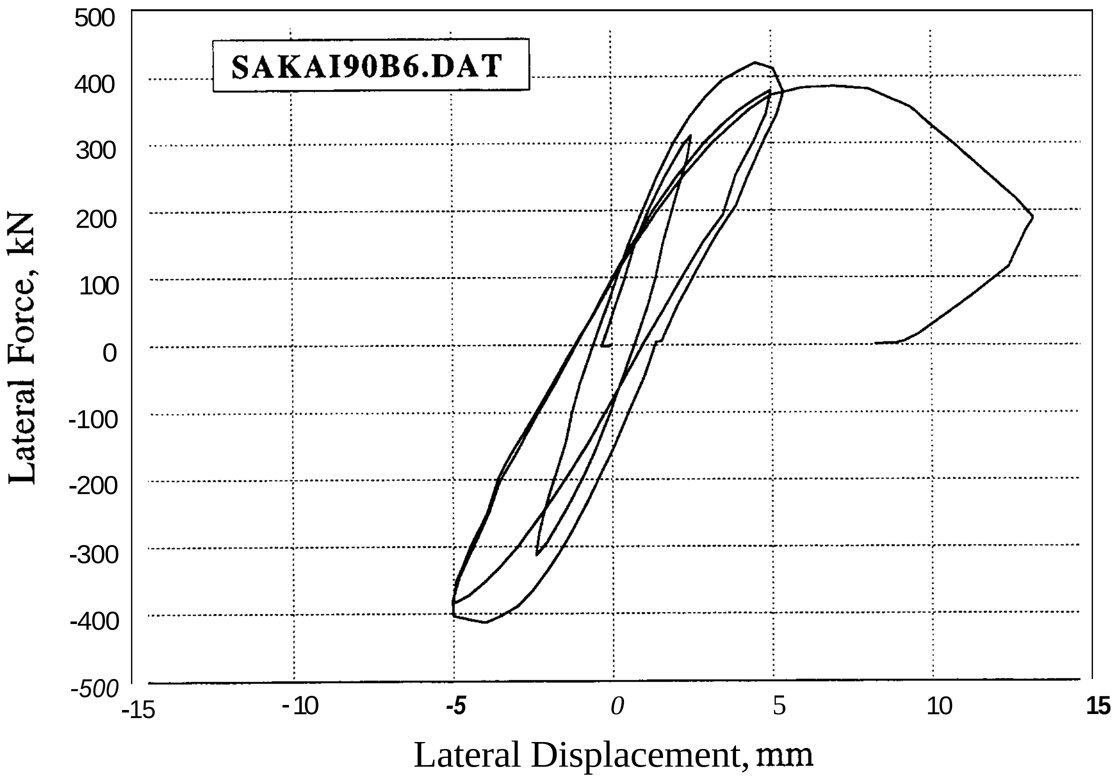


Figure 71. Specimen **B6 of** *Sakai* 1990

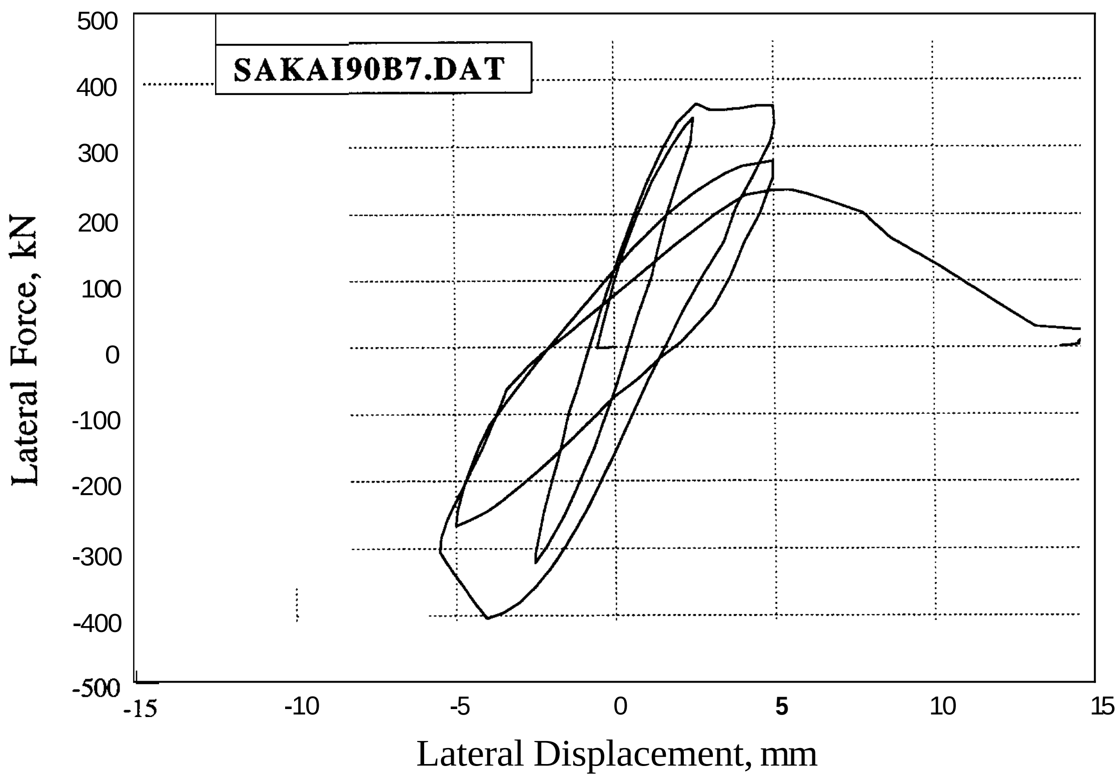


Figure 72. Specimen B7 of *Sakai* 1990

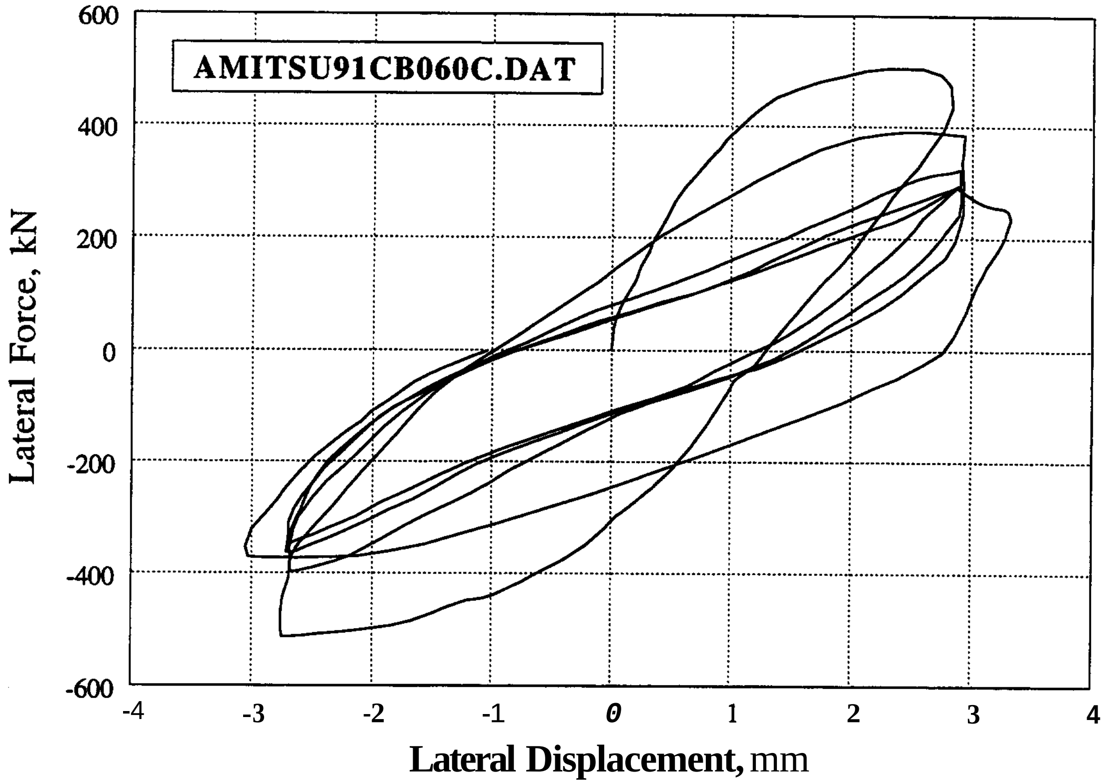


Figure 73. Specimen CB060C of Amitsu 1991

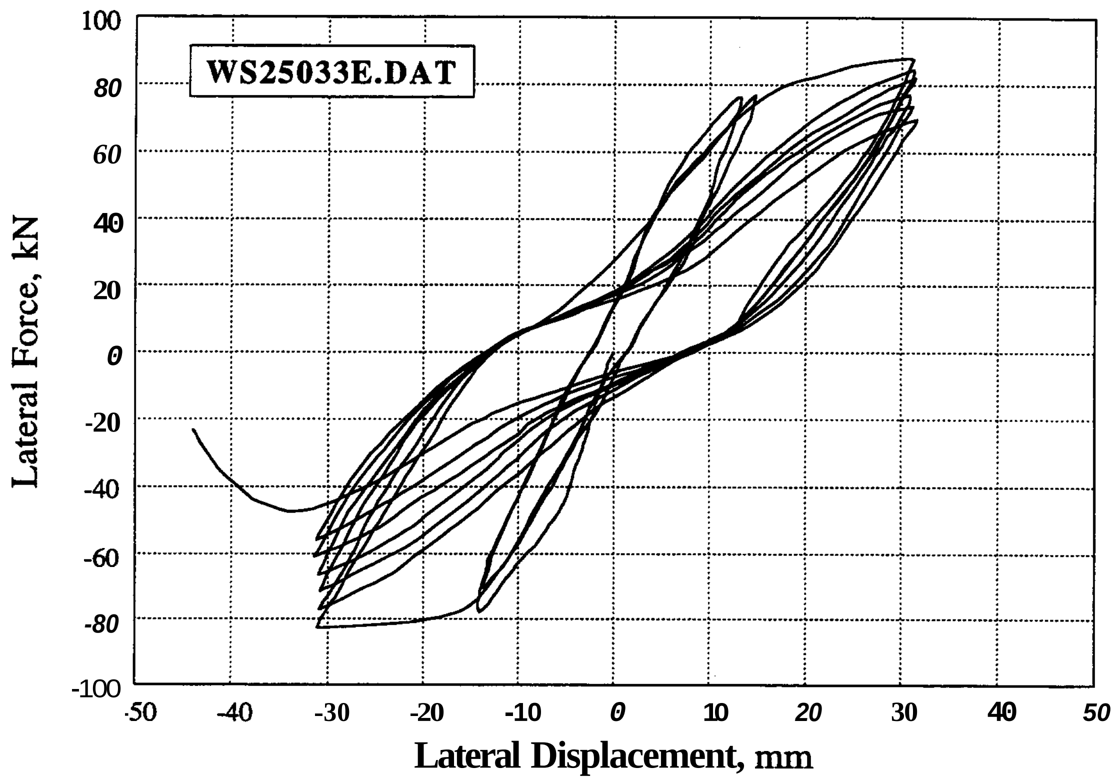


Figure 74. Specimen WS25033E of Wight 1973

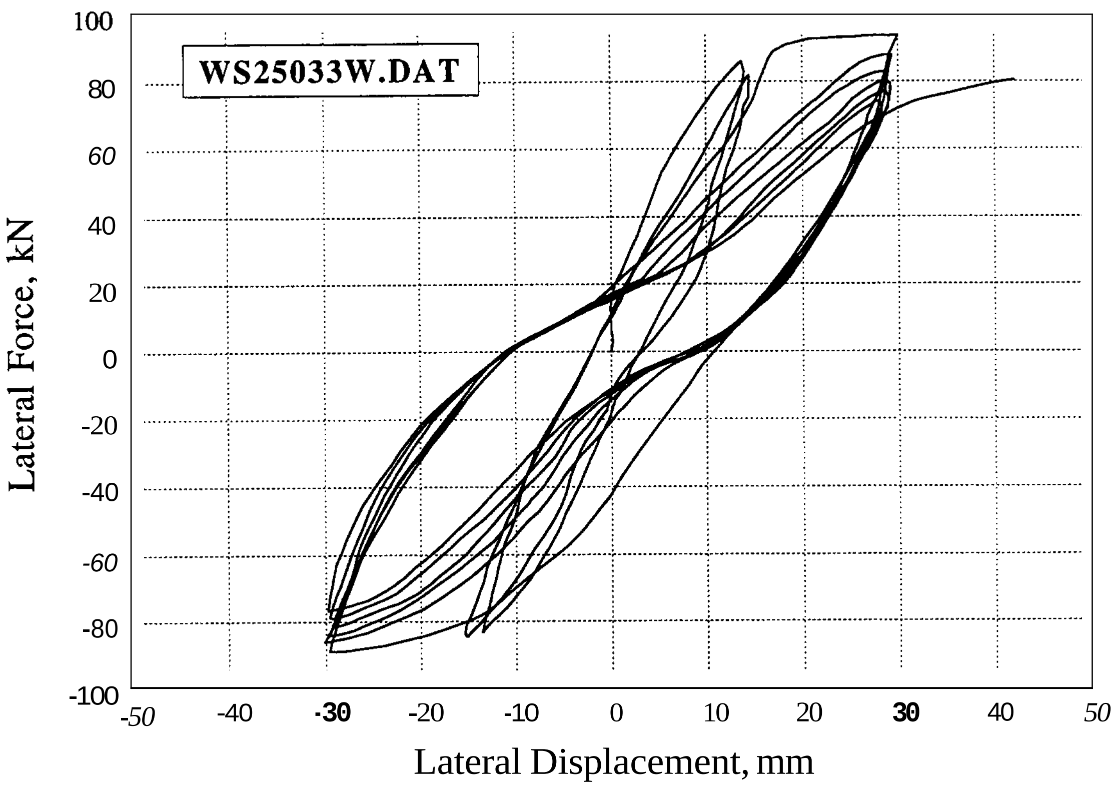


Figure 75. Specimen WS25033W of Wight 1973

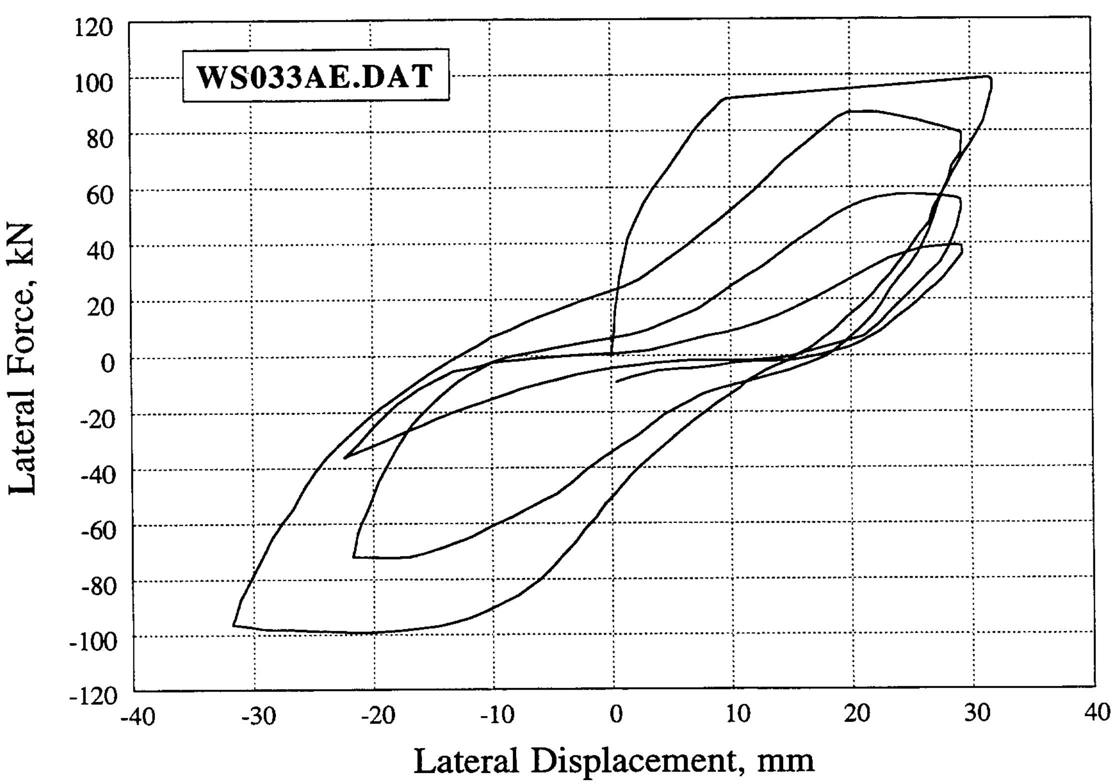


Figure 76. Specimen WS033AE of Wight 1973

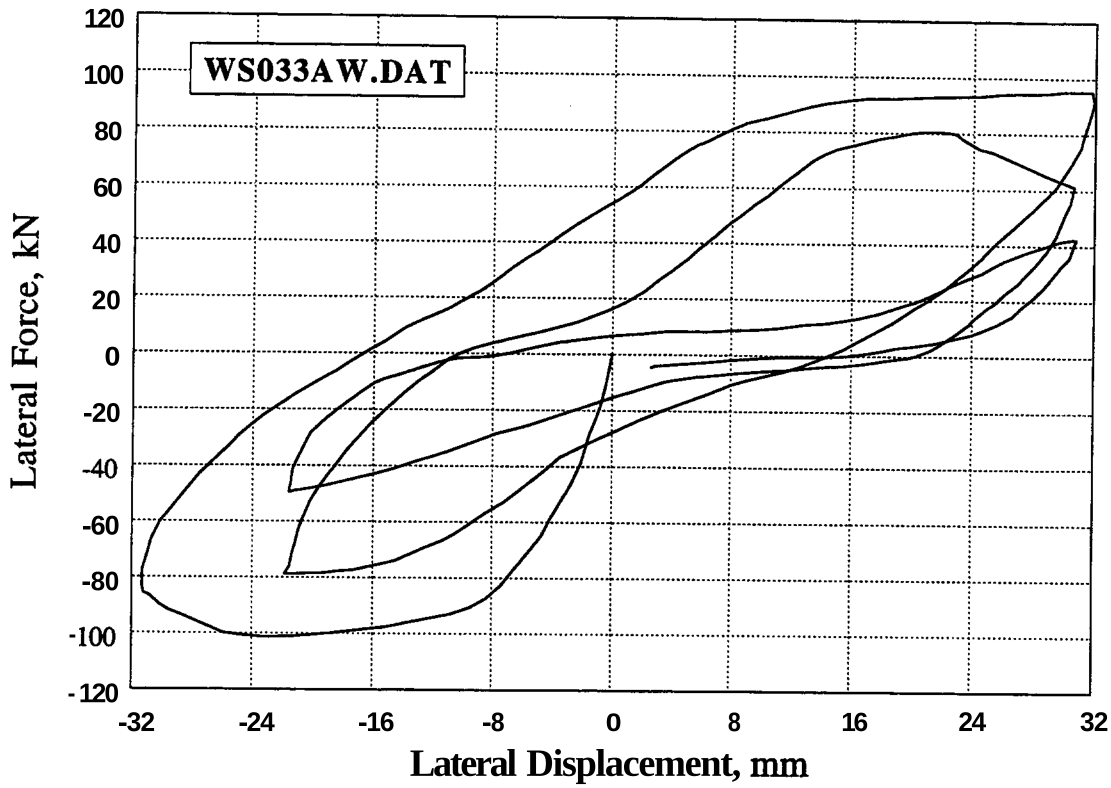


Figure 77. Specimen WS033AW of Wight 1973

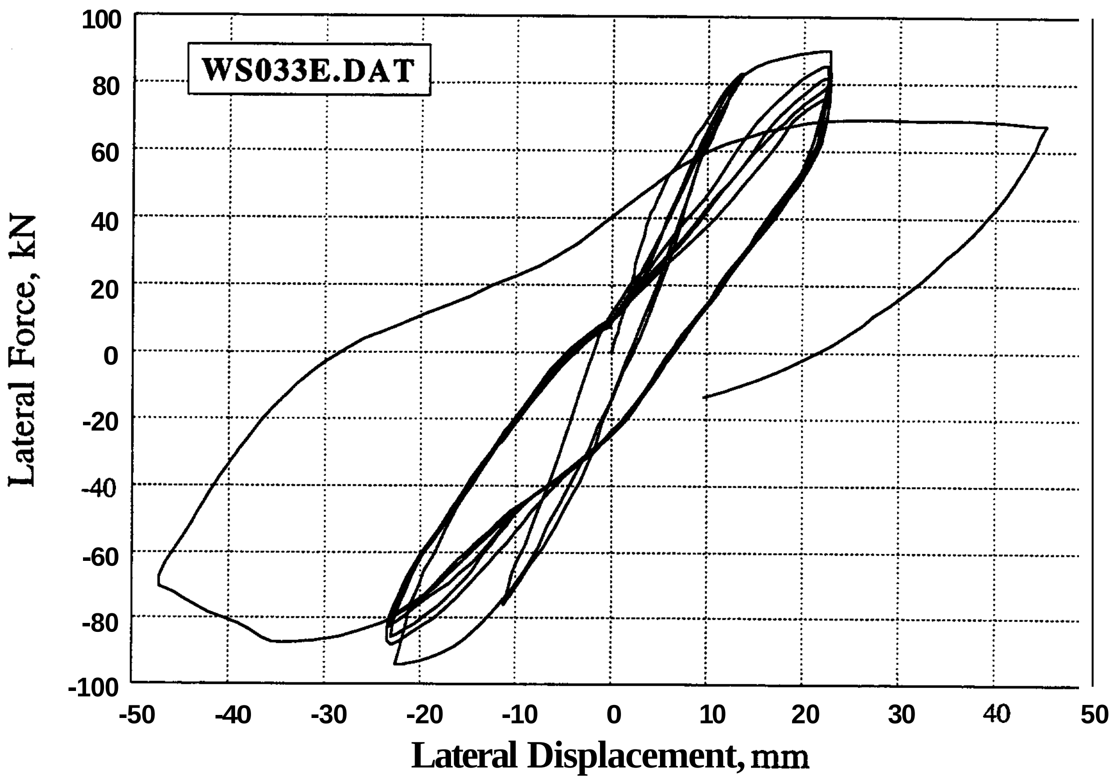


Figure 78. Specimen WS033E of Wight 1973

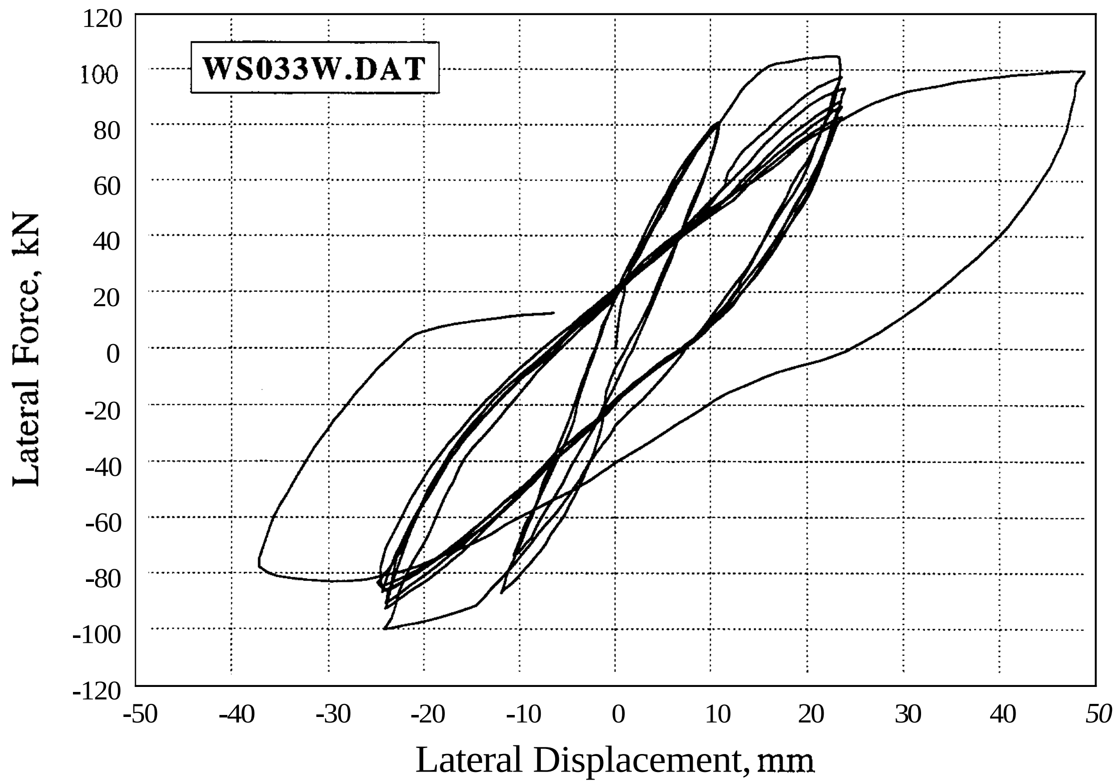


Figure 79. Specimen WS033W of Wight 1973

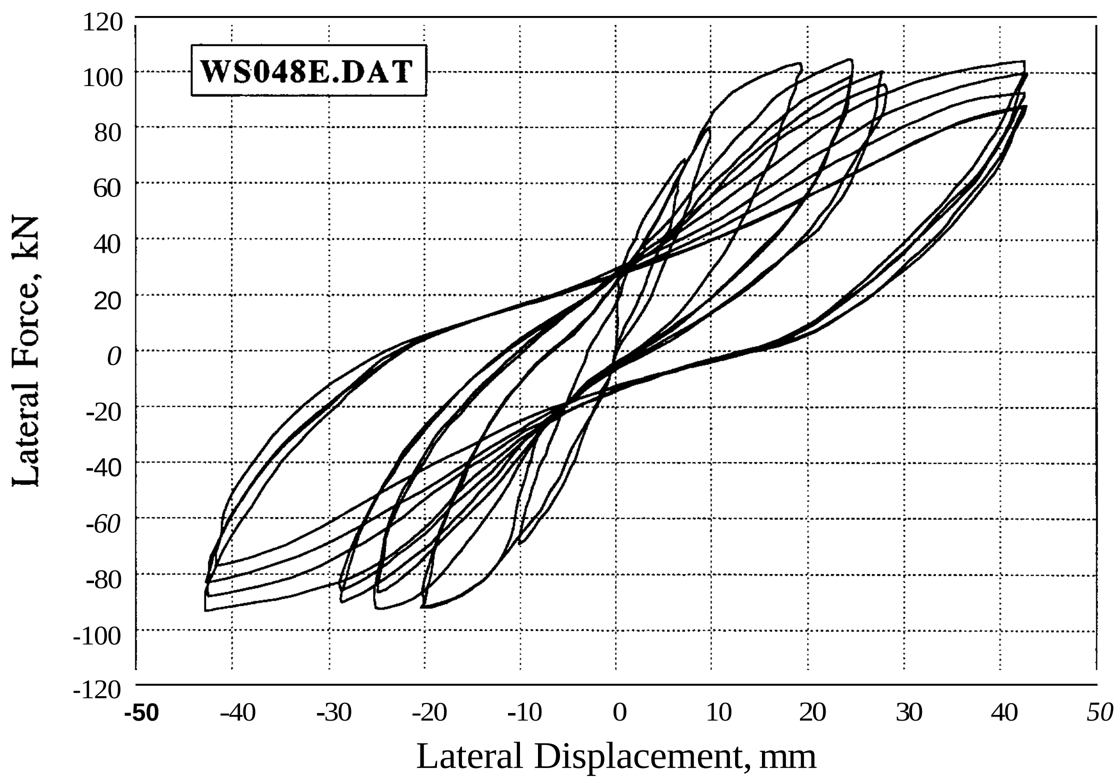


Figure 80. Specimen WS048E of Wight 1973

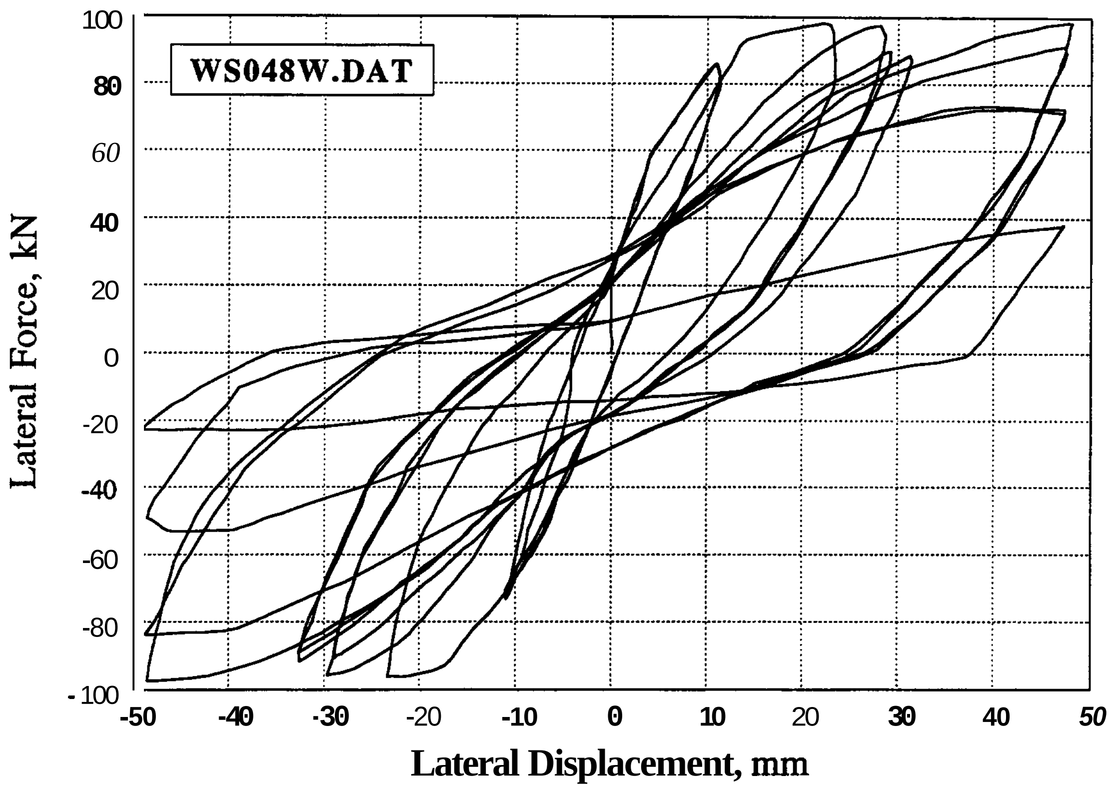


Figure 81. Specimen WS048W of Wight 1973

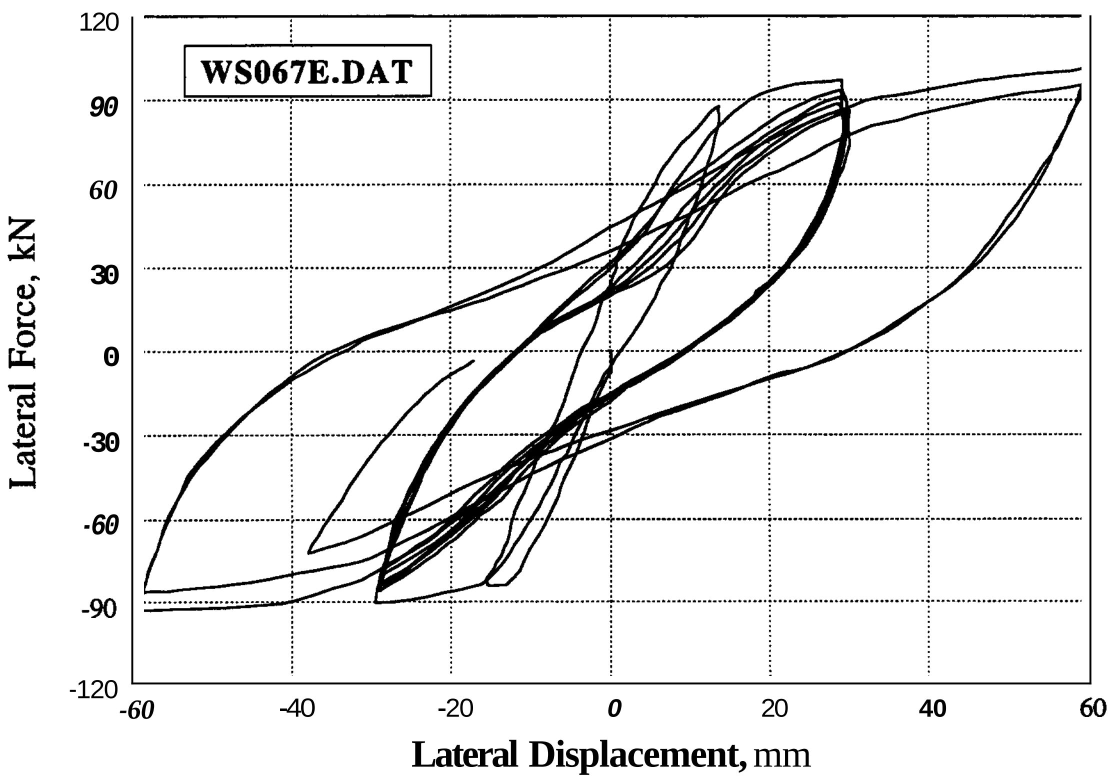


Figure 82. Specimen WS067E of Wight 1973

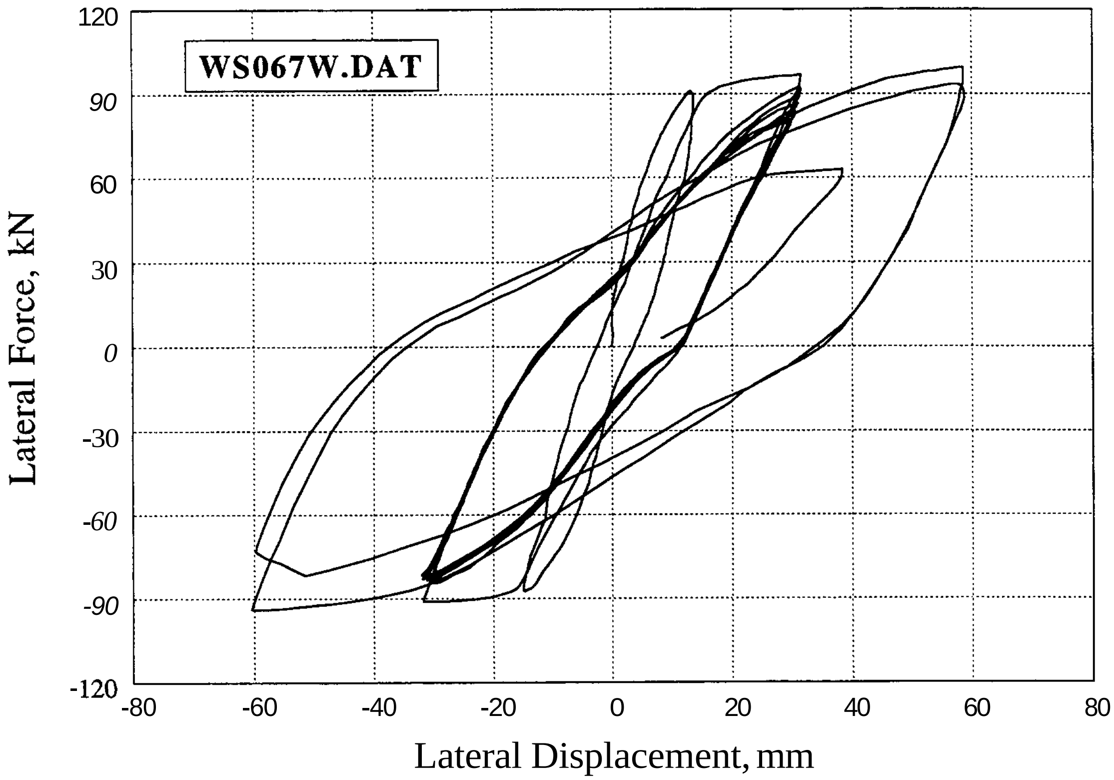


Figure 83. Specimen WS067W of Wight 1973

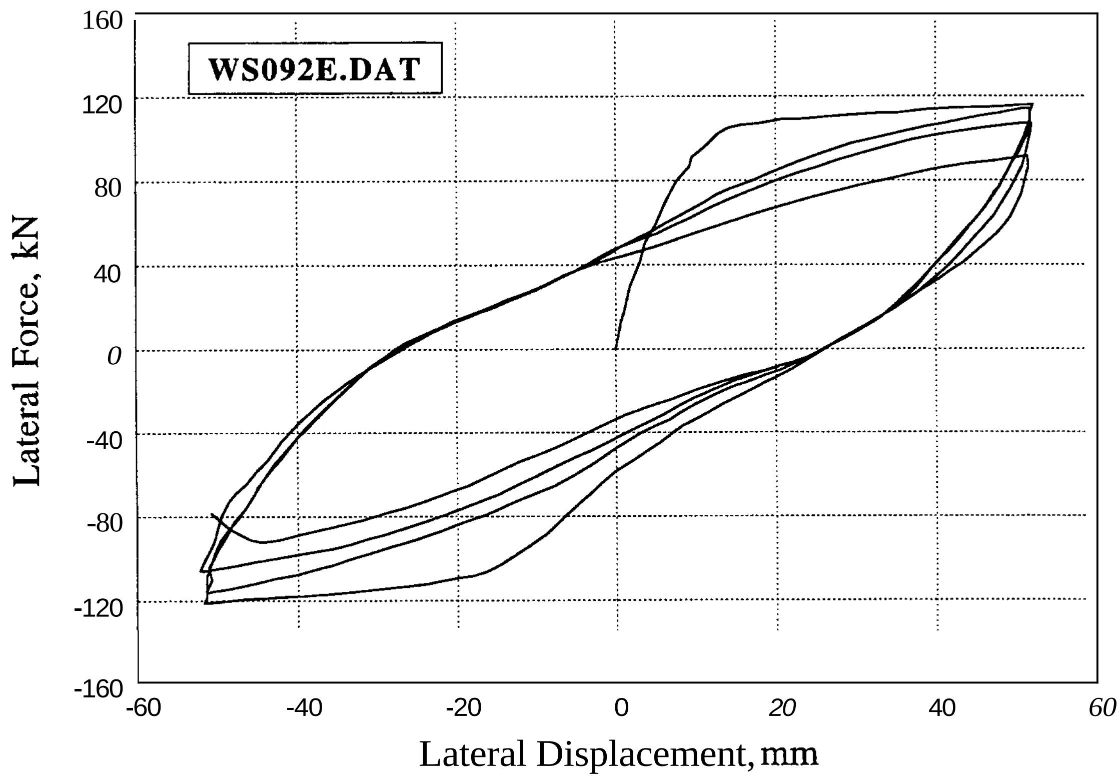


Figure **84.** Specimen WS092E of Wight 1973

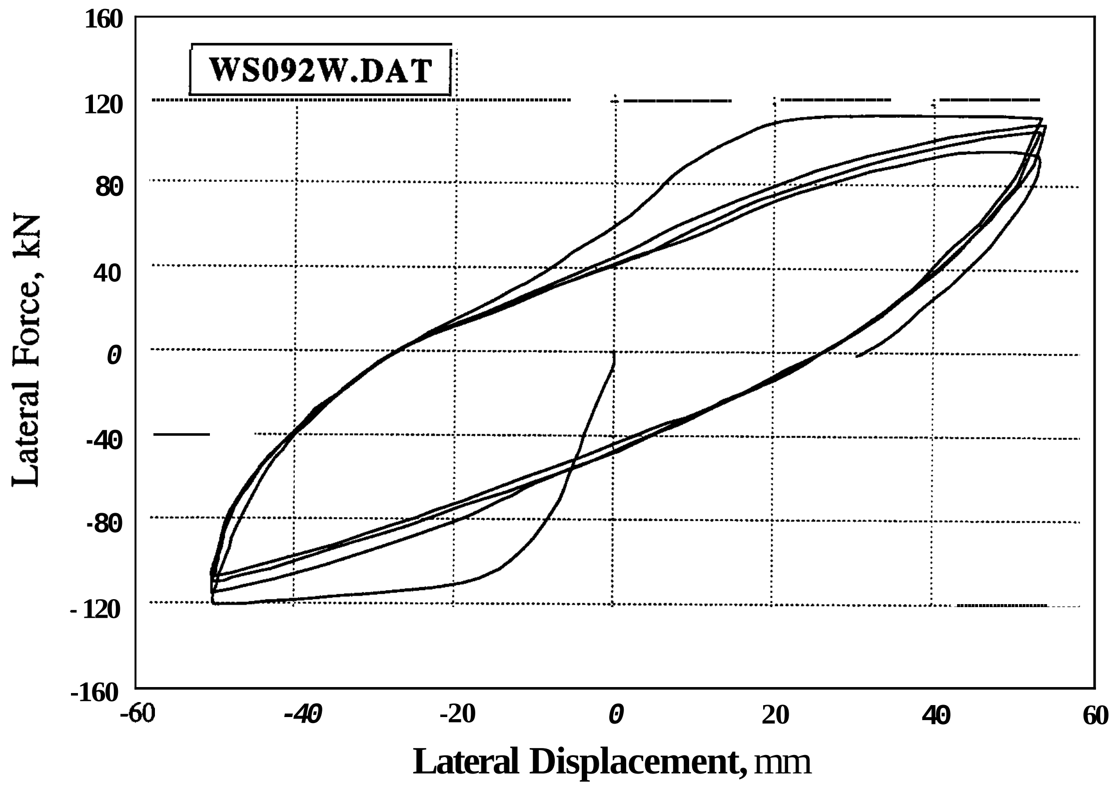


Figure 85. Specimen WS092W of Wight 1973

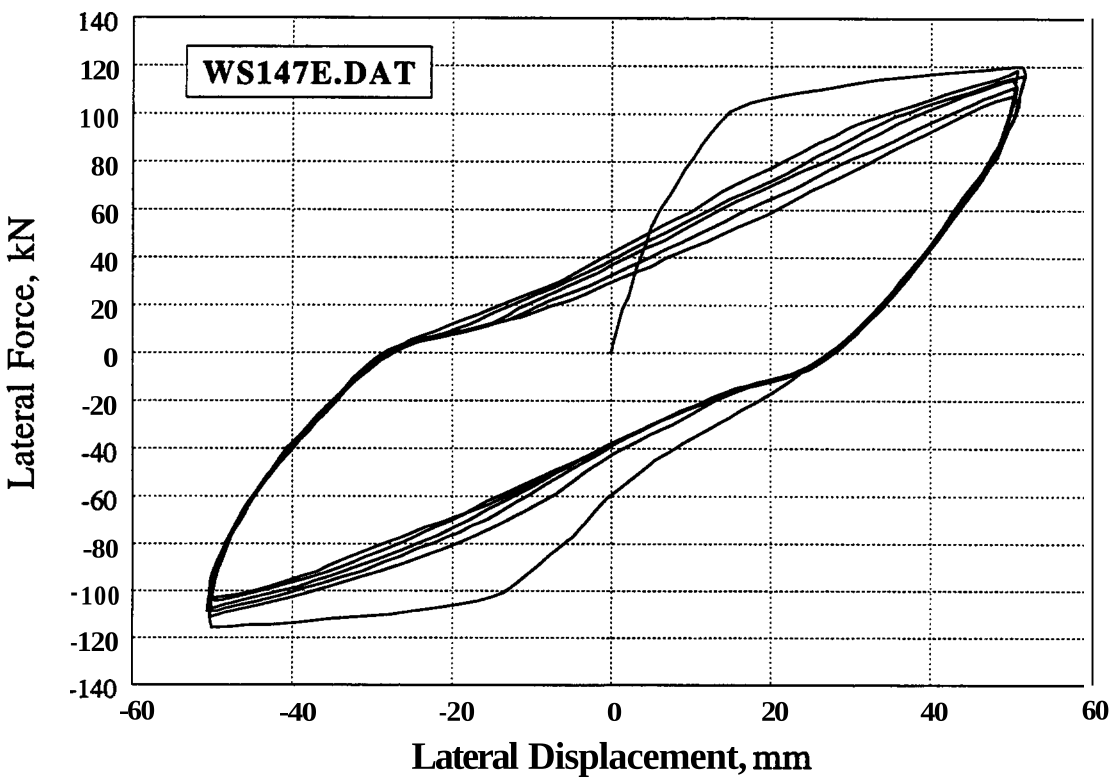


Figure 86. Specimen WS147E of Wight 1973

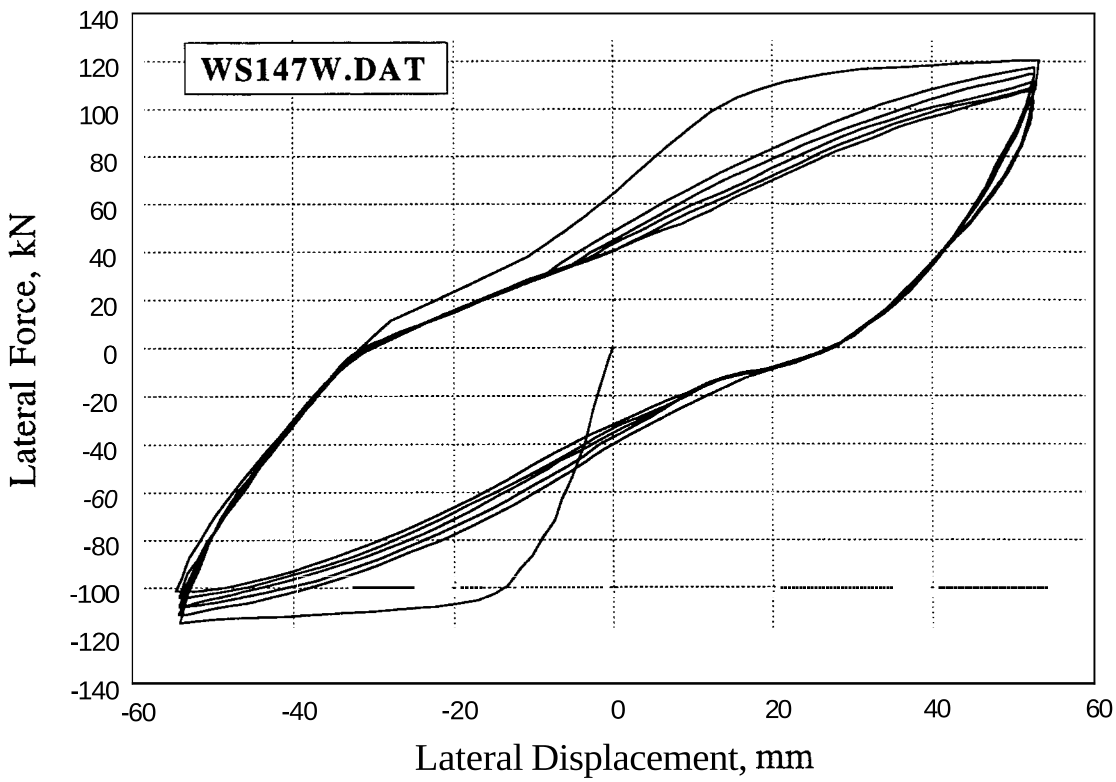


Figure 87. Specimen WS147W of Wight 1973

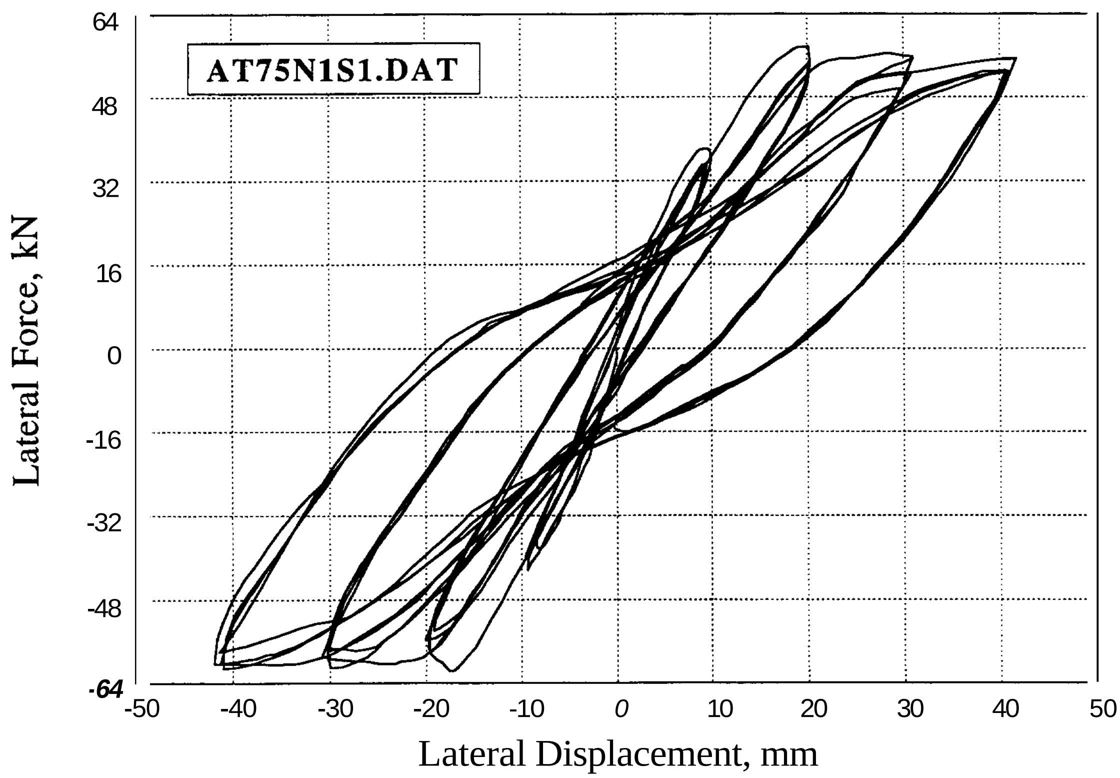


Figure 88. Specimen 1 of Atalay 1975

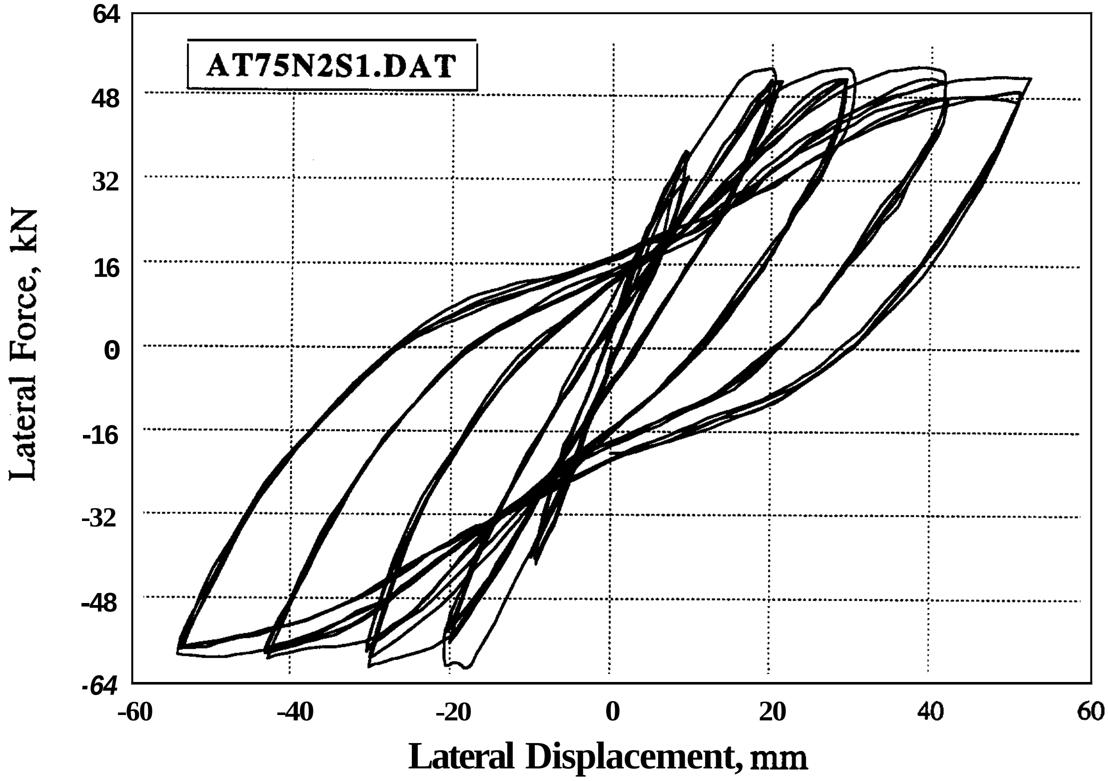


Figure 89. Specimen 2 of Atalay 1975

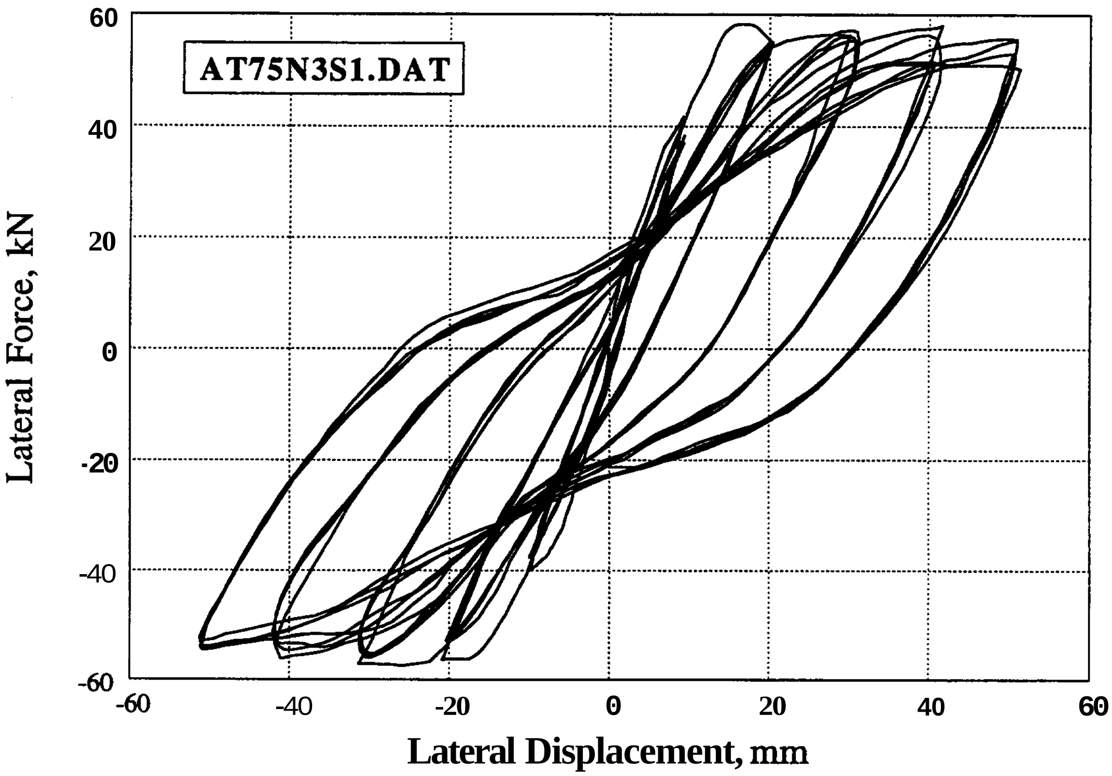


Figure 90. Specimen 3 of Atalay 1975

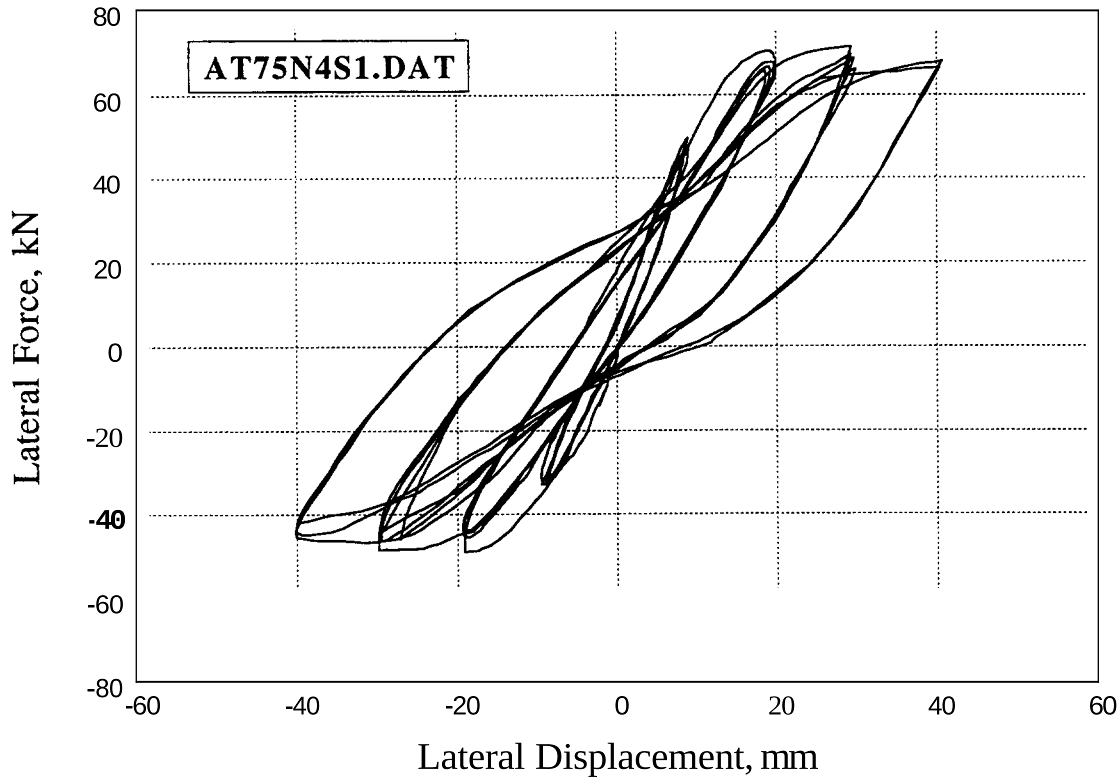


Figure 91. Specimen **4** of Atalay 1975

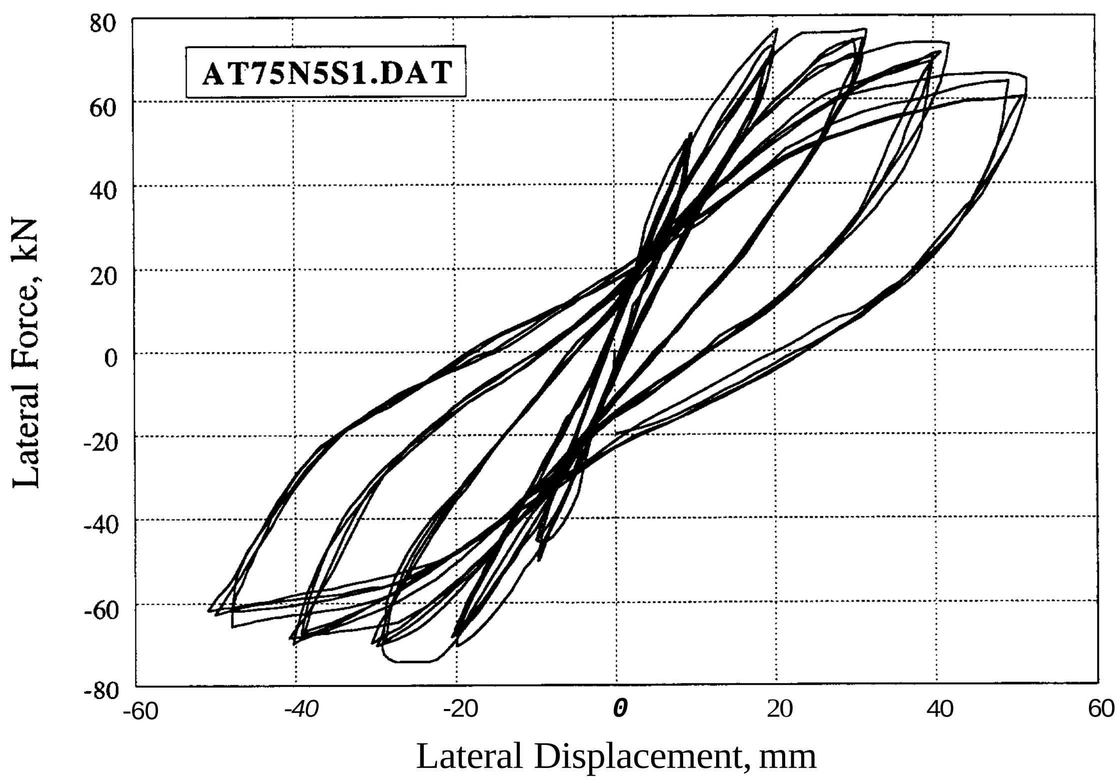


Figure **92.** Specimen 5 of Atalay 1975

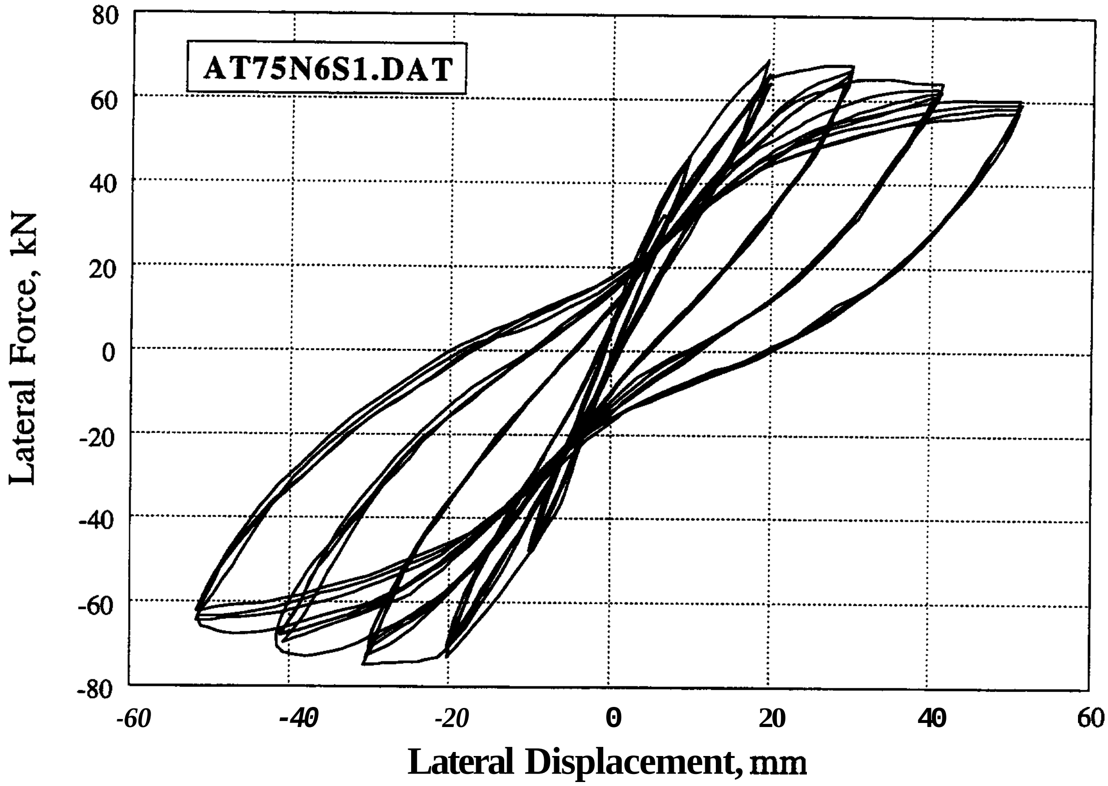


Figure 93. Specimen 6 of Atalay 1975

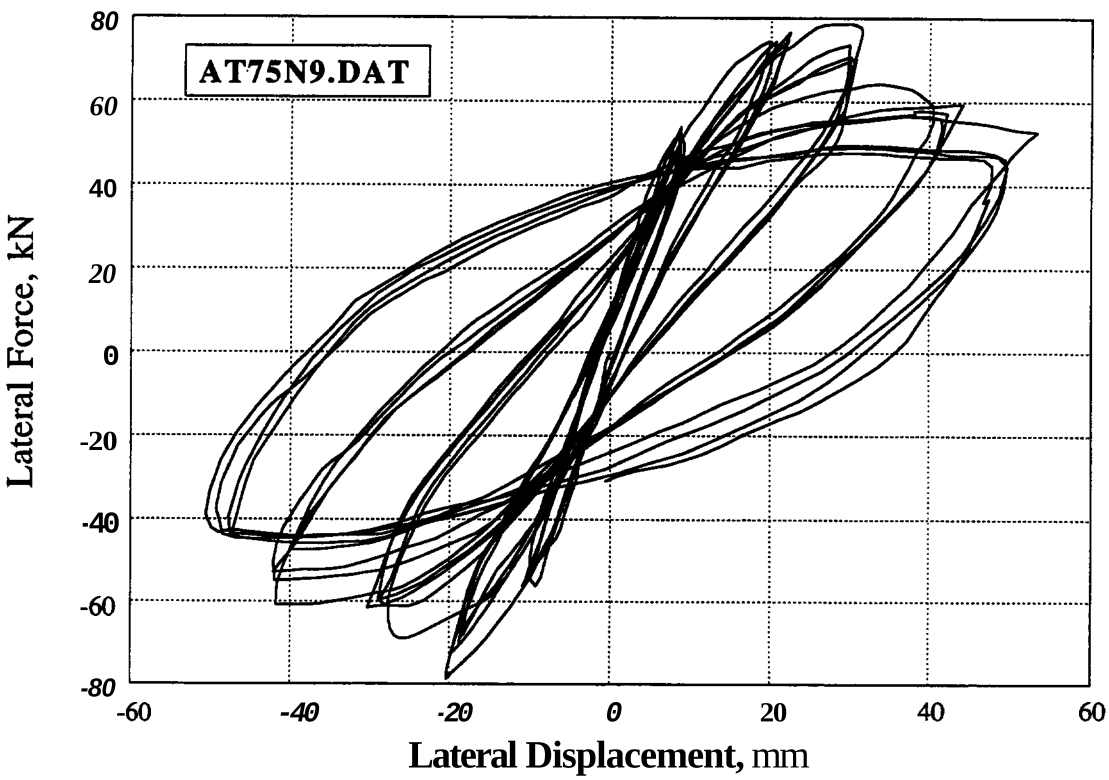


Figure 94. Specimen 9 of Atalay 1975

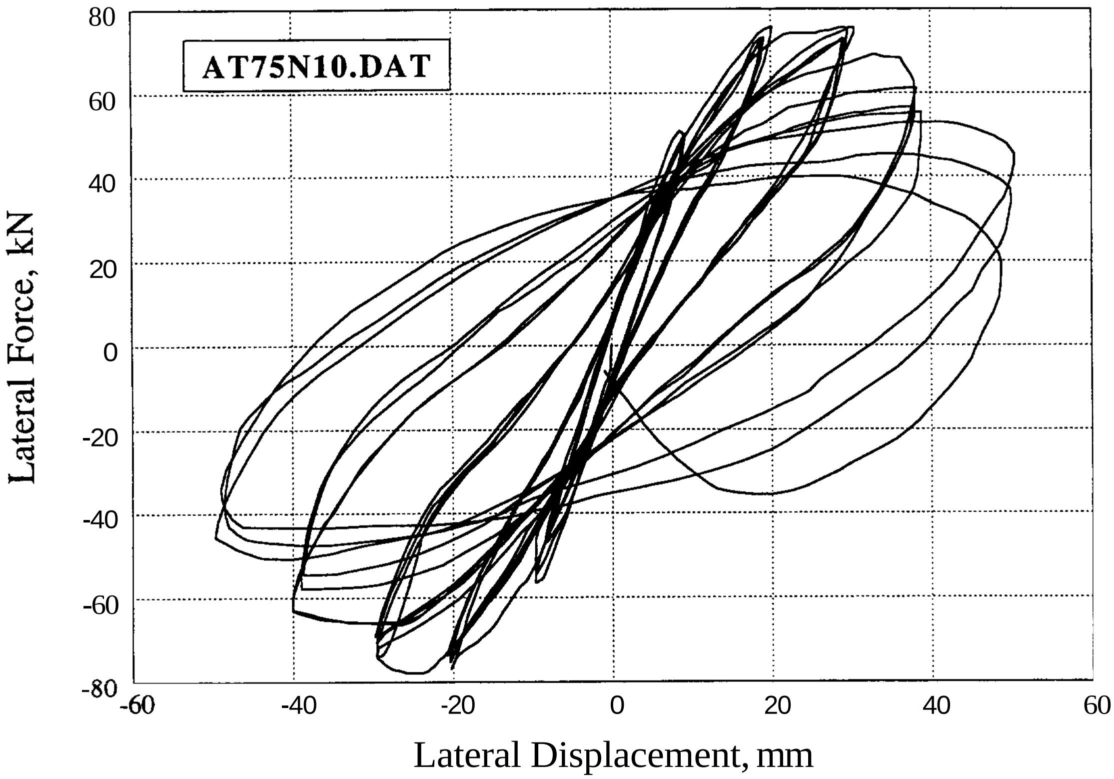


Figure 95. Specimen 10 of Atalay 1975

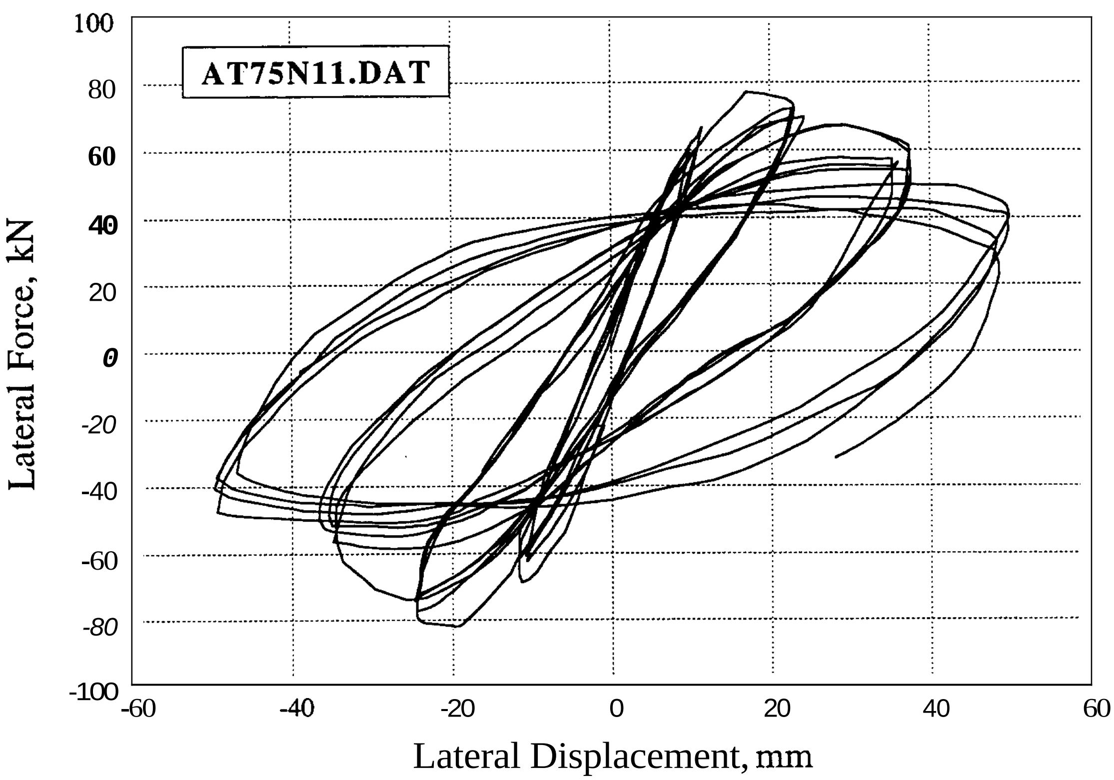


Figure 96. Specimen 11 of Atalay 1975

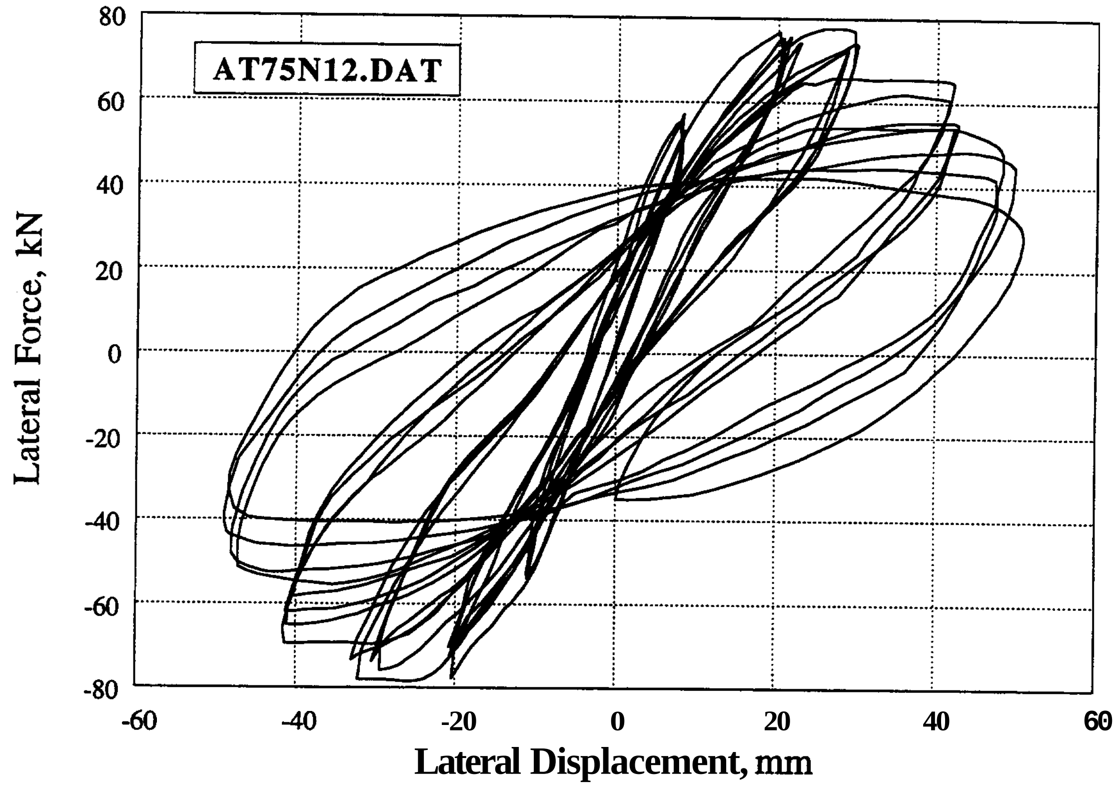


Figure 97. Specimen 12 of Atalay 1975

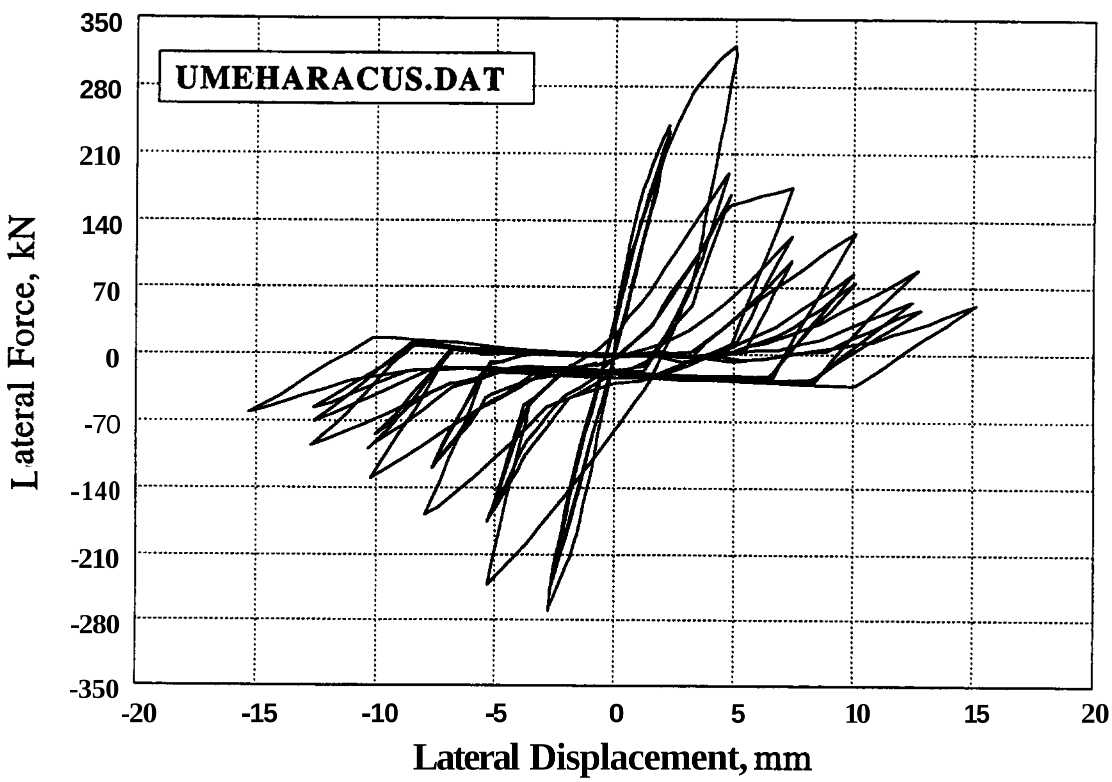


Figure 98. Specimen CUS of Umehara 1982

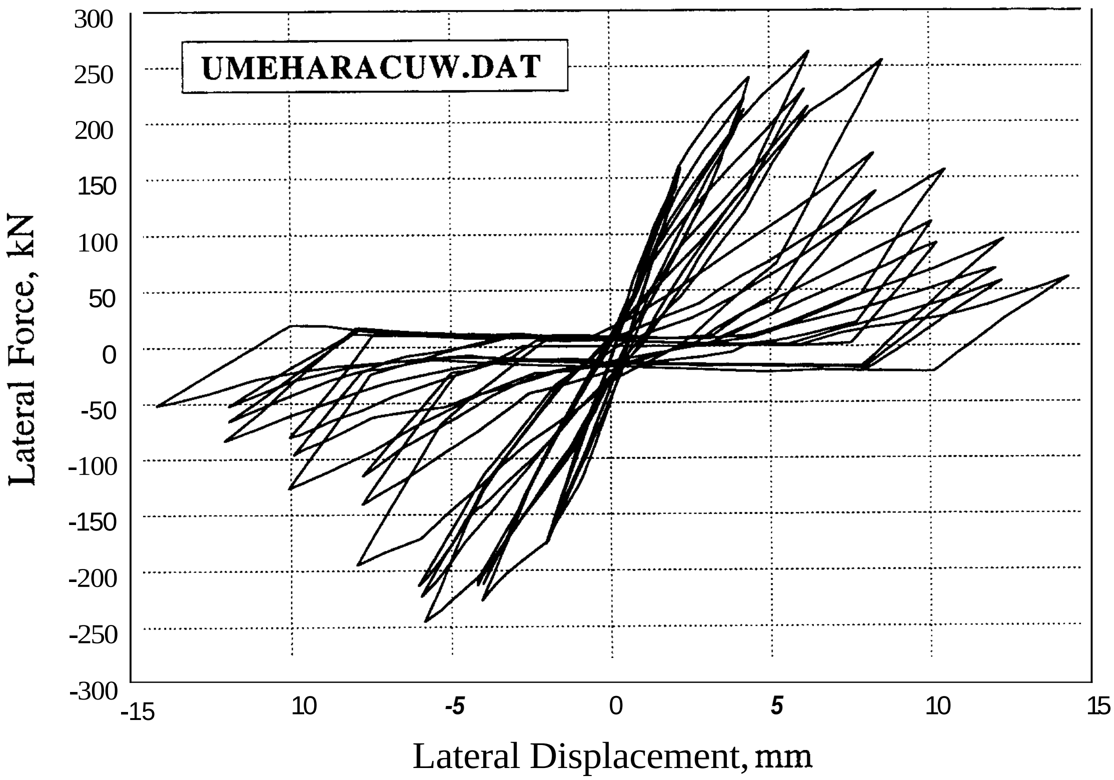


Figure 99. Specimen CUW of Umehara 1982

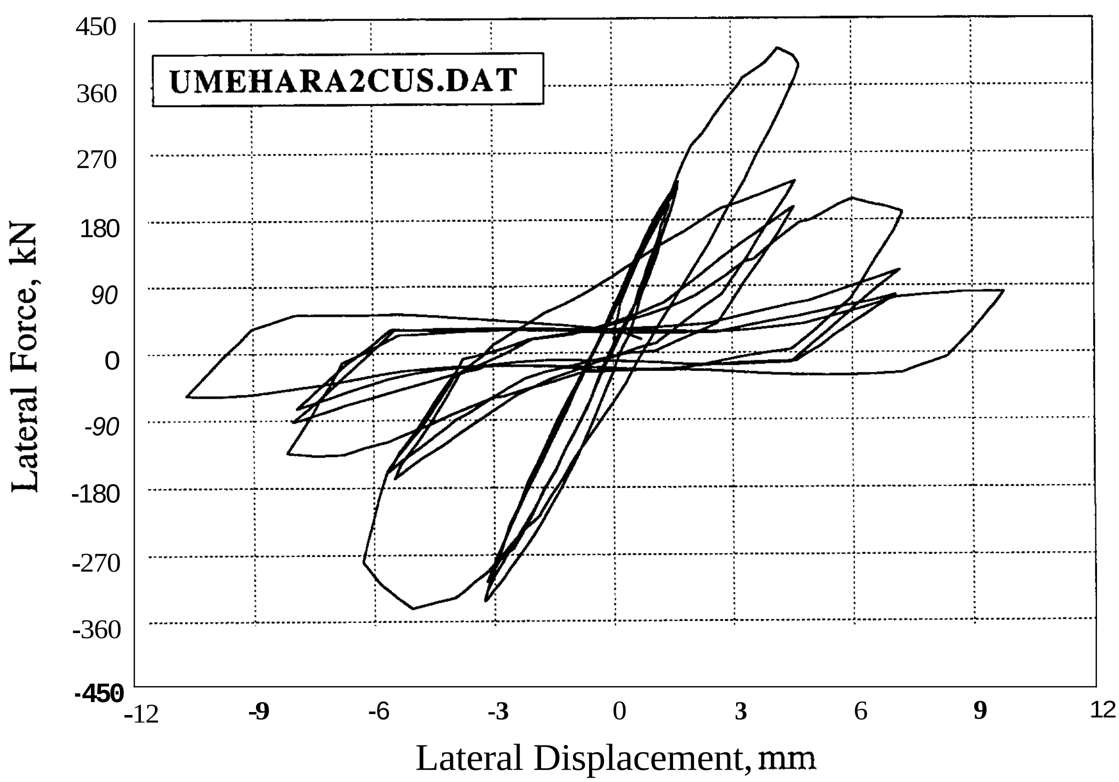


Figure 100. Specimen 2CUS of Umehara 1982

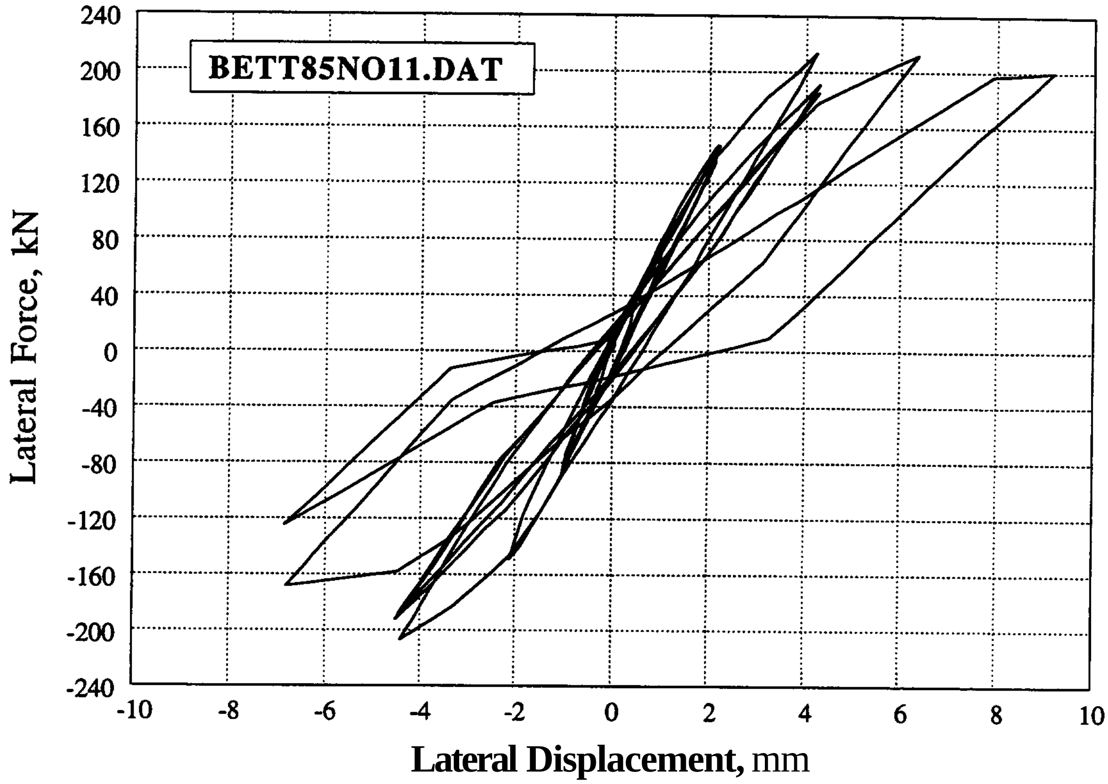


Figure 101. Specimen 11 of Bett 1985

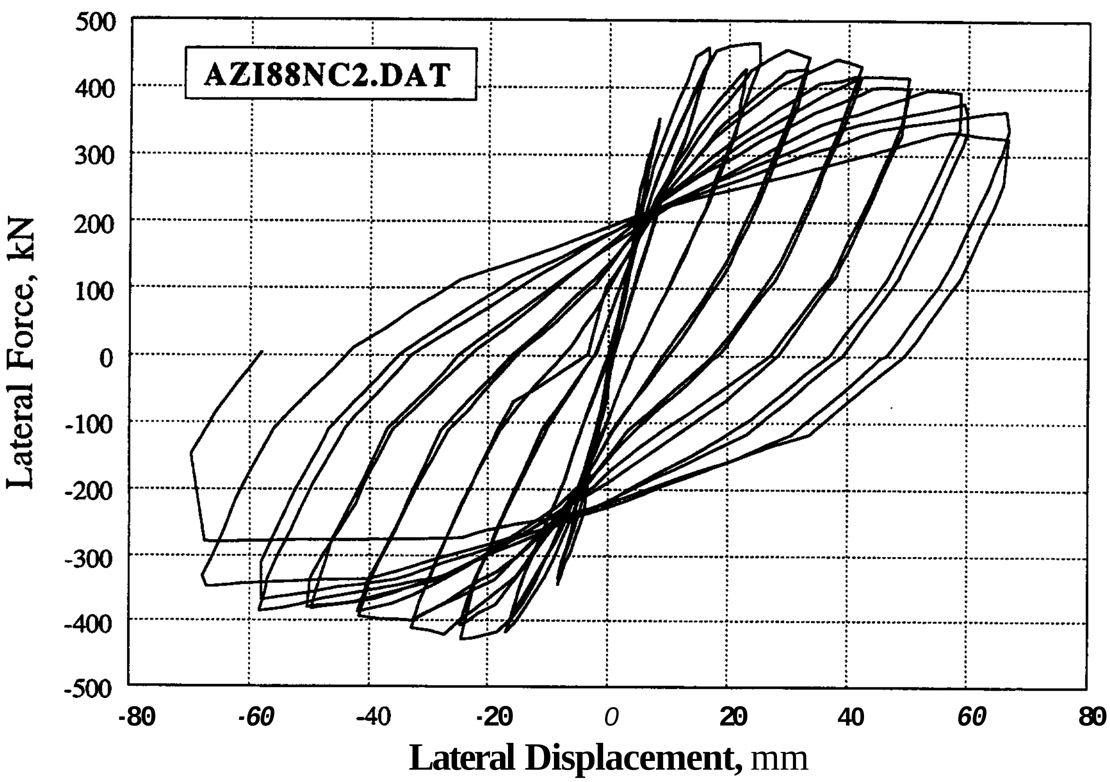


Figure 102. Specimen NC-2 of Azizinamini 1988

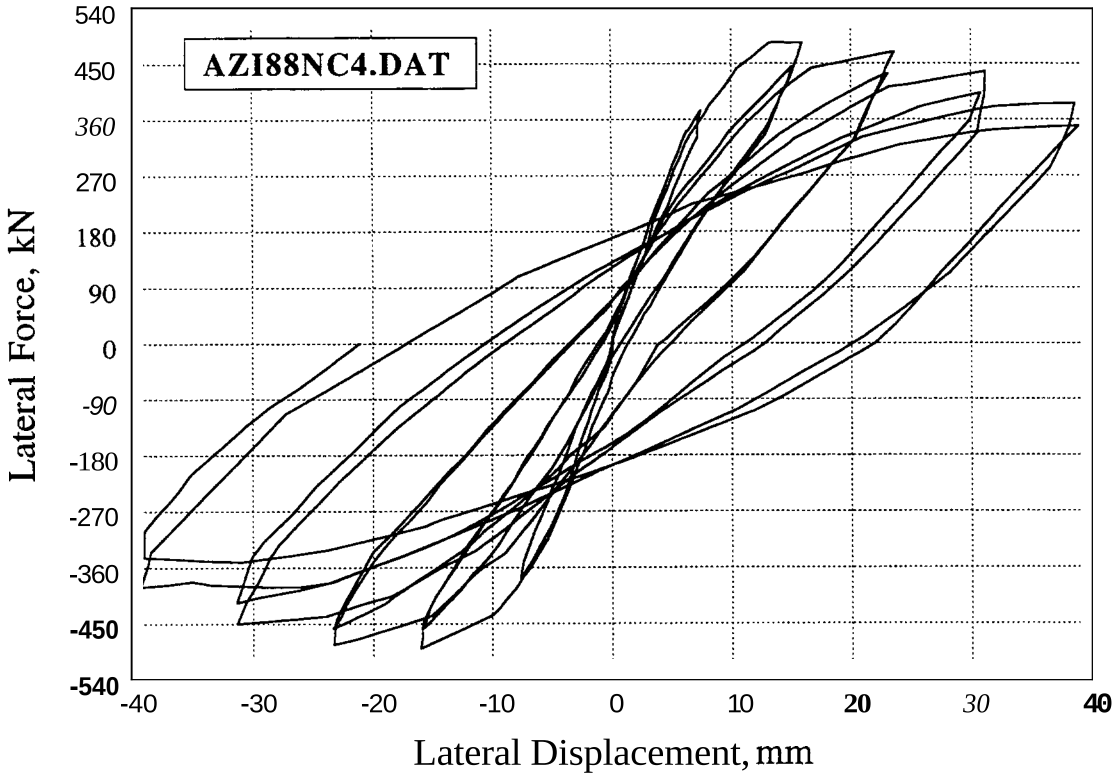


Figure 103. Specimen **NC-4** of Azizinamini 1988

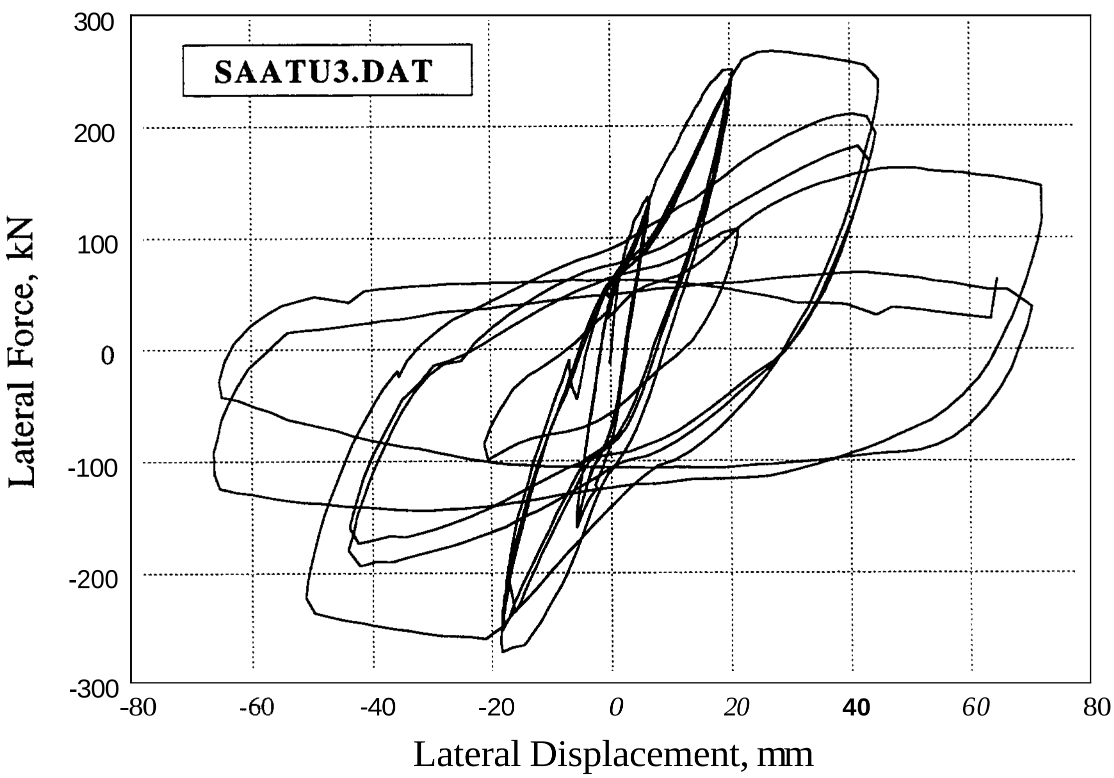


Figure 104. Specimen **U3 of** Saatcioglu **and** Ozcebe 1989

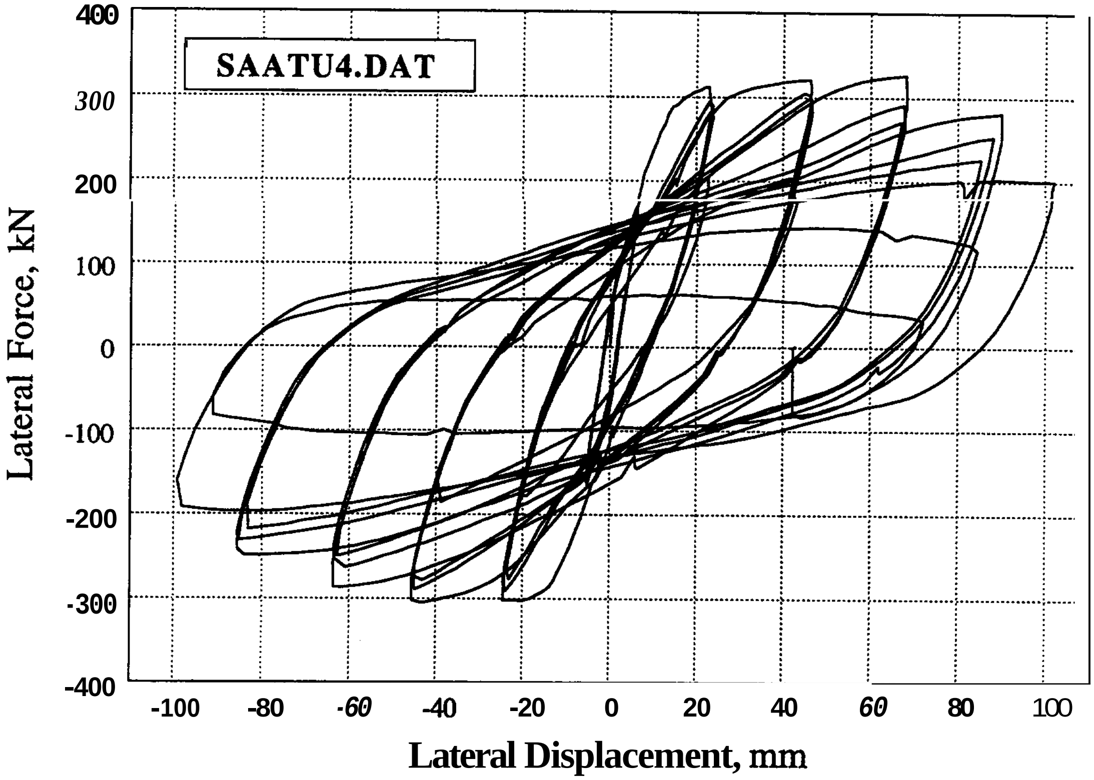


Figure 105. Specimen U4 of Saatcioglu and Ozcebe 1989

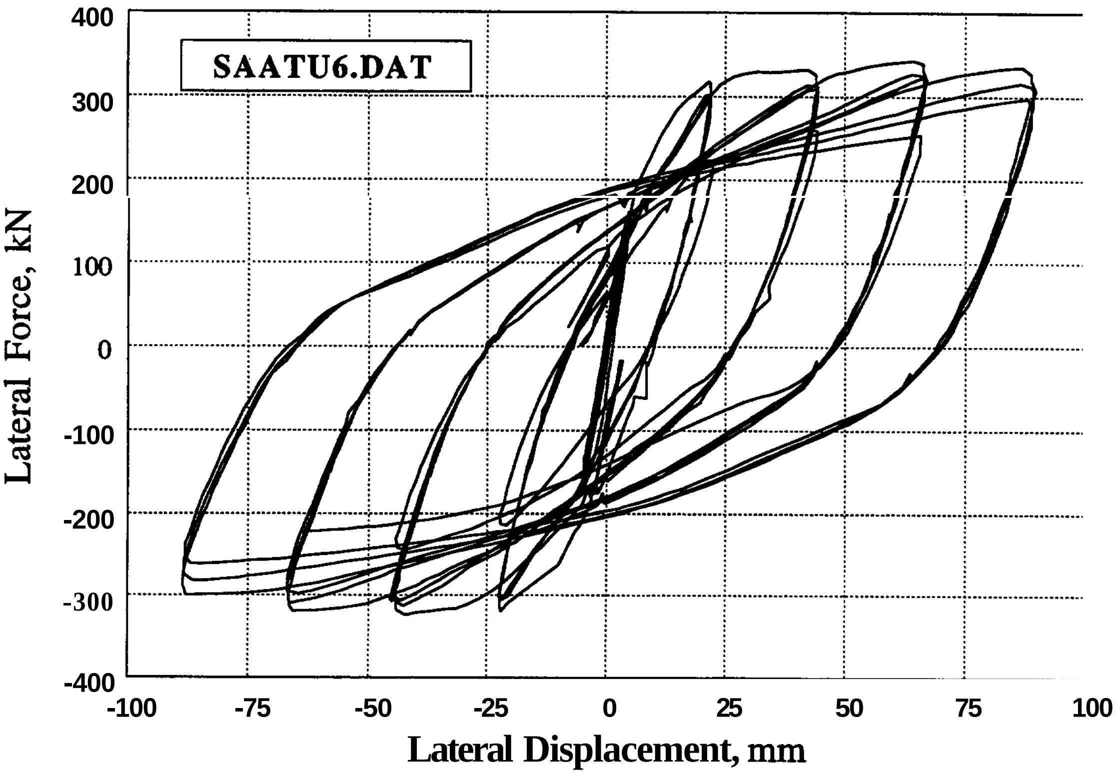


Figure 106. Specimen U6 of Saatcioglu and Ozcebe 1989

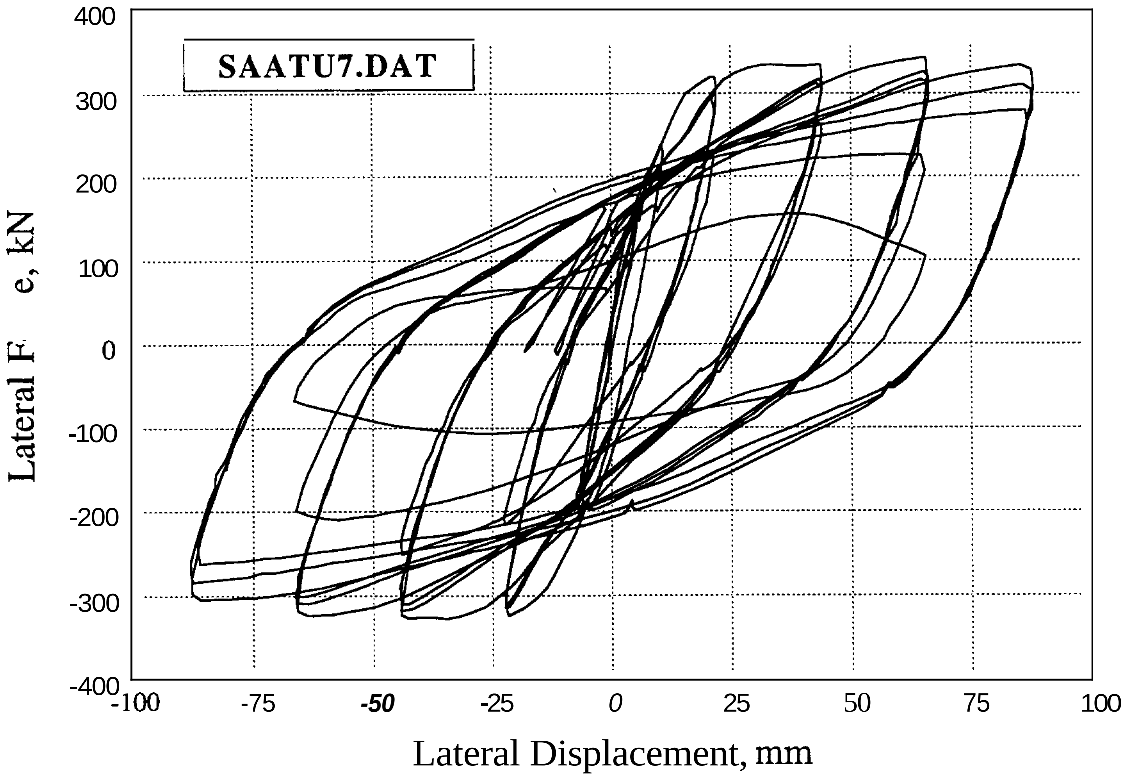


Figure 107. Specimen **U7** of Saatcioglu and Ozcebe 1989

Chapter 4: Digital Data Files

Enclosed is one high density (1.44 megabytes) DOS compatible disk. The disk contains 107 digital data files listing lateral deflection-lateral force data, as described in this report.

The files are stored on the disk in a compressed format. To decompress the files, first copy the only file on the disk, RECTCOL.EXE onto the computer hard disk. There should be at least 3 megabytes of disk space available to perform the expansion. Then type the command

RECTCOL.EXE

and all of the files will be automatically decompressed. The original compressed files, RECTCOL.EXE, may then be erased from the hard disk.

The names of the 107 digital data files correspond to those given in Chapter *2* of the report. All the data files (once they have been de-compressed) are in a format which is readable by common spreadsheet programs. The first line of each file is a short descriptive title. The second line is the total number of deflection-force data pairs, "n", to follow in the data file (i.e., the number of data points in the file). The remaining "n" lines are the deflection-force data pairs, in units of mm and kN.